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ABSTRACT

The governments of the United States, Japan, West Germany, France, and the United Kingdom each have large research and development efforts involving government agencies, universities and industry. This document provides a comparative overview of policies and programs which contribute to the development of technologies in the general area of electronics and materials. The report provides: (1) an overview of investments in science and technology in each country; (2) descriptions of how each country is organized for research and development in science and technology; (3) an overview of each government's developmental programs in electronics and materials technologies; (4) a description of government policies involving private sector research and technology; and (5) profiles of United States federal government funding in nine research areas that have been targeted by the Japanese government as high-risk, requiring large investments of time and money. Included is a section which describes the methodologies used to collect the data for this report. (TW)

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REPORT BY THE U.S.

General Accounting Office

Support For Development Of Electronics And Materials Technologies By The Governments Of The United States, Japan, West Germany, France, And The United Kingdom

The governments of the United States, Japan, West Germany, France, and the United Kingdom each have large research and development efforts involving government agencies, universities, and industry. Each government has strongly supported electronics technology since the 1960's, and all have started major programs to develop new electronics technologies since 1981. As part of broader materials development efforts, all five governments are supporting research in ceramics, composite materials, polymers, and rapid solidification metallurgy.

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WASHINGTON, D.C. 20548

RESOURCES, COMMUNITY
AND ECONOMIC DEVELOPMENT
DIVISION

B-217847

The Honorable Lloyd Bentsen
Vice Chairman, Subcommittee on
Economic Goals and
Intergovernmental Policy
Joint Economic Committee
Congress of the United States

Dear Mr. Vice Chairman:

In your February 8, 1983, letter, you requested that we provide information on how much research and development (R&D) the U.S. government was conducting or funding in the 12 specific areas of electronics, materials, and biotechnology[1] that had been selected for support by the Japanese government. In subsequent discussions with your office, we agreed to (1) prepare a comparative overview of government policies and programs in the United States, Japan, West Germany, France, and the United Kingdom that can contribute to the development of technologies in the general areas of electronics and materials and (2) provide information on how much R&D the U.S. government has been funding in 9 of the 12 areas designated in the original request.

To provide background and perspective on governmental efforts to develop electronics and materials technology, we agreed to obtain information about each country's overall investment in, and organization to support, research and development. We also agreed to provide information on governmental policies that can influence private sector R&D.

We found that all five governments have large R&D efforts involving government agencies, universities, and industry and that all have started major programs to develop new electronics technologies since 1981. There are differences among the countries, however, in the emphasis of their R&D efforts. R&D is a large part of governmental efforts of the United States, France, and the United Kingdom, but not of Japan or West Germany. Japan, in many respects, and West Germany, to a lesser degree, are restrained by post-World War II arrangements from maintaining massive strategic and conventional defense structures. Government R&D relationships with industry and universities also are less centralized in the United States than they are in the other four countries.

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[1] As agreed, we did not develop information on the three biotechnology areas in the original request because of ongoing work in the Office of Technology Assessment. Information on biotechnology is contained in the Office of Technology Assessment's report Commercial Biotechnology - An International Analysis (OTA-BA-218, January, 1984).

Government efforts to develop specific industries through "industrial policies" have attracted popular interest and led to political controversy in the United States. Academic studies often identify the government support for R&D described in this report as part of industrial policies. We found that the information available on U.S. governmental R&D activities was scattered and fragmentary. By providing an overview of governmental support for R&D in the five countries, we believe that our report can help clarify this aspect of industrial policies.

Our report describes each government's organization, funding levels, and program strategies for R&D. It does not contain judgments about the effectiveness of programs and strategies or how well they are being implemented, because of the lack of necessary information and the lack of generally accepted measures for judging R&D output or effectiveness.

Methodological problems and major structural differences create uncertainties in comparing R&D programs among the five countries. For example, the lack of adequate price indexes to compare expenditures among countries creates uncertainty in judging the relative level of research performed in each country. In addition, several consultants who reviewed our report noted that it is very difficult to compare large defense-related research efforts in the United States with civilian-oriented efforts in other countries. Defense R&D is not directed toward general commercialization. Defense expenditures may contribute to commercial technology in a spin-off effect, but how much actually occurs has not been measured.

To compare overall R&D activities, we used standardized data compiled by the Organization for Economic Cooperation and Development (OECD) and the National Science Foundation. Because OECD data are compiled from several countries, the latest comparable data is often several years old. Program information on each country was compiled primarily from government documents and supplemented by other information sources, including published studies and interviews with U.S. government officials, representatives of foreign governments, professional association staff, and academic researchers. (Methodology is described in more detail in appendix VII.)

NATIONAL INVESTMENTS IN RESEARCH AND DEVELOPMENT BY THE UNITED STATES, JAPAN, WEST GERMANY, FRANCE, AND THE UNITED KINGDOM

Together, the United States, Japan, West Germany, France, and the United Kingdom perform about 85 percent of all research and development by the 24 members of the Organization for Economic Cooperation and Development.[2] Organization members perform almost all the R&D for non-Communist countries. Each of the five governments supports a large range of R&D activities and hopes to advance in practically all fields of knowledge. All five have created extensive relationships among government agencies, universities, and private industry for performing publicly funded R&D. Japan and West Germany have increased their R&D spending faster than the United States, but the United States still spends as much as the other four countries combined.

Chart 1 shows the total national R&D expenditures (by government, industry, and universities) in each country as a proportion of gross national product (GNP). In the early 1960's, R&D was a much higher proportion of GNP in the United States and the United Kingdom than of Japan, West Germany, and France. By the late 1970's differences among the countries were smaller. In 1983 the United States, Japan, and West Germany devoted about 2.6 percent of their GNP to R&D. Because detailed data are not available to show trends in the nine specific areas of electronics and materials research identified in the request letter, we do not know whether these areas follow the trends shown in chart 1.

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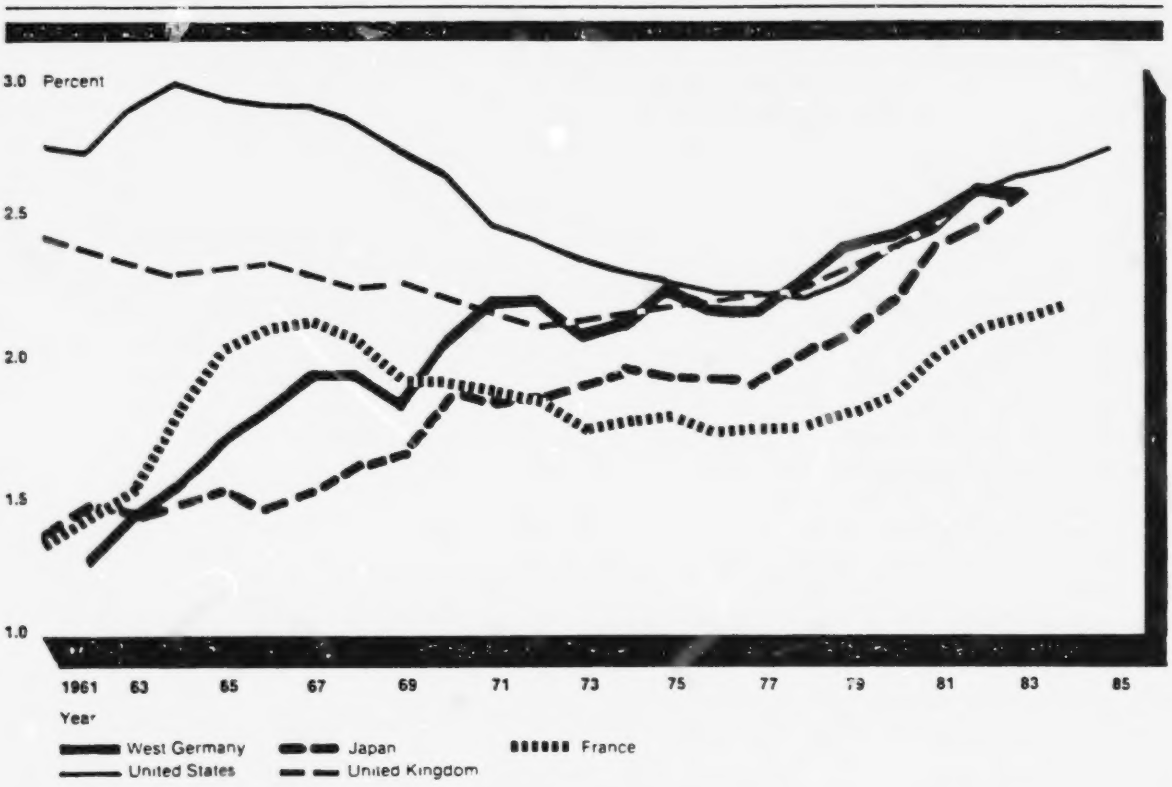
[2] The Organization for Economic Cooperation and Development is an international organization that performs studies and other cooperative activities, chiefly on economic matters.

CHART 1

National Expenditures For Performance of Research and Development As a Percentage of Gross National Product by Country: 1961-85



Note The latest data (1980-1985) may be preliminary or estimated. Missing years not available.

Source National Science Foundation, International Science and Technology Data Update, Jan. 1985

As chart 2 shows, the United States' total R&D expenditures are far greater than any of the other four countries. In 1981, the last year in which data are available for all countries, U.S. expenditures were greater than those of the other four countries combined.

Chart 2

National Expenditures for Research and Development, 1981

(billions of U.S. dollars)

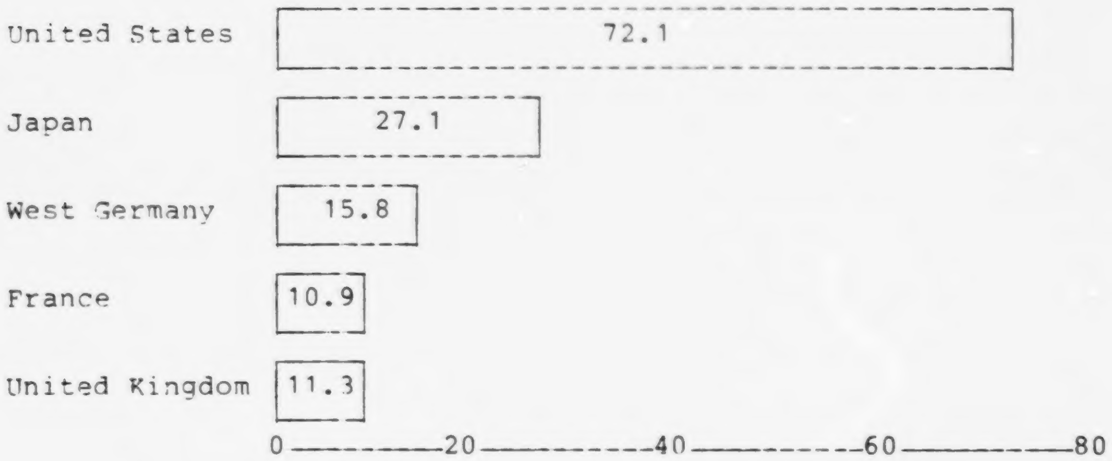


Table 1 shows both total and civilian R&D expenditures as a proportion of GNP. West Germany and Japan devote a larger proportion of GNP to civilian R&D than the United States, France, and the United Kingdom.

Table 1
Research and Development
In Relation To Gross National Product
(1981 data)

		Percent GNP
Country	All R&D	Civilian R&D
West Germany	2.5	2.4
United States	2.4	1.9
Japan	2.4	2.4
United Kingdom	2.5	1.7
France	2.0	1.7

Source: National Science Foundation International Science and Technology Data Update, January 1985.

The United States employs the largest number of scientists and engineers in R&D, both in absolute numbers and in proportion to its total work force. Over the past 15 years, both Japan and Germany have greatly increased the proportion of their workers engaged in R&D. (See appendix I for additional information on national investments in R&D.)

GOVERNMENT SUPPORT FOR RESEARCH AND DEVELOPMENT

The five governments differ in how they are organized to support R&D. The United States has a decentralized approach to dealing with industry and universities that involves several government agencies. In the United States there is no single agency with broad responsibility for supporting the development of technology for use by industry, although the National Institutes of Health, the National Science Foundation, and the Departments of Defense, Energy, and Agriculture support significant amounts of university research. Japan, West Germany, France, and the United Kingdom have more centralized approaches; one or two agencies support R&D by universities and industry. In Japan, for example, the Ministry of International Trade and Industry is primarily responsible for working with industry to develop technology, while the Ministry of Education supports university research. (The overall organization of each government for support of science and technology is described in appendix II.)

GOVERNMENT PROGRAMS TO DEVELOP ELECTRONICS TECHNOLOGY

Each government has strongly supported electronics technology since the 1960's, particularly for use in computers. Since 1981, all five governments have announced new spending plans to advance electronics technology. These new plans focus on developing and applying very large scale integrated circuits,[3] which will have higher performance levels and much lower costs than the circuits used now. The governments plan to use very large scale integrated circuits to advance computer capability for purposes such as artificial intelligence and computer-aided design and manufacturing. Summary information on the main spending plans follows in table 2.

In addition to these specific plans, the governments make other efforts to develop electronics technology, such as supporting university research, performing research at government laboratories, and funding industry efforts to develop and apply electronics technology. Private industry also supports electronics R&D in each country. In 1983, U.S. industry spent about $7.7 billion in R&D on computers, semiconductors, and related equipment while Japanese industry spent about $2.2 billion on R&D in the same areas, according to U.S. government estimates. We were not able to obtain estimates of European industrial investments in electronics R&D.

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[3] Definitions of this and other technical terms are contained in the glossary.

The U.S. government is spending less on efforts to develop nondefense electronics technology than the other four governments. We identified about $80 million in U.S. government support for electronics technology not directly related to defense, while each of the other four countries is spending more than $100 million a year to develop nondefense electronics technology.

Table 2
Main Plans to Advance Electronics Technology

Country	Date announced	Duration (years)	Total cost	Description
Japan	1981	12	$500 million[a]	Basic Technology for Electronic Computers (Fifth Generation Computer) project. This project seeks to use very large scale integrated circuits to apply artificial intelligence research and make computers that can translate language, serve as interactive reference libraries, and create computer software automatically.
France	1982	5	$ 26 billion[b]	Five Year Electronics Plan. The cost of the French effort is not comparable to other listed programs because it includes all capital investment, in addition to R&D costs. Support for nationalized industries is the highest priority, to compete with Japan and the United States. Computer-aided design for very large scale integrated circuits, computer-aided design and manufacturing, and software using artificial intelligence concepts were announced as major R&D objectives, along with other areas.
United Kingdom	1983	5	$300 million[c]	Program for Advanced Information Technology. The program focuses on four key technologies: very large scale integrated circuits, computer programming, better interaction between people and computers, and systems that can apply knowledge through inference.
United States	1983	5	$600 million	Strategic Computing Program. The program is to develop a broad base of electronic and information technology for national security and economic growth, including high-performance device technology, very large scale integrated systems, computer architecture, and artificial intelligence applications.
West Germany	1983	5	about $1.1 billion[d]	Microelectronics Research Program. To make West German industry more competitive with Japan and the United States, the government will support R&D in microelectronics, advanced computers, office automation, communications, robotics, and other areas.

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[a] Cost not announced; outsiders estimate $500 million.

[b] About 140 billion francs, including investments as well as R&D.

[c] 200 million pounds in government funds.

[d] 3 billion marks.

Defense research gives electronics technology a high research priority in the United States, France, and the United Kingdom, but in West Germany and Japan, defense programs are of less importance. In recent years the United States and the United Kingdom spent at least half of government R&D funds on defense; in comparison, France spent 40 percent; Germany, 14 percent; and Japan, 5 percent. The United States spends more on defense electronics research than any of the other four governments.

The Japanese government is concentrating on long-term, large-scale electronics development projects for high-speed scientific computing, artificial intelligence, and other related applications. The goals of the three European governments are to overcome the United States' and Japan's current commercial advantage in the electronics and computer industries. The three European countries are also taking part in a European community[4] program to help member countries compete against United States and Japanese industry. The program, called the European Strategic Program of Research and Development in Information Technology (ESPRIT), will last 5 years and cost member governments about $640 million.

Government efforts to develop electronics programs are affected by differences in the electronics and computer industries among countries. U.S. corporations, which dominated the early development of computers and integrated circuits, have been able to finance large amounts of R&D on their own. (Two industrial associations have been formed since 1982 to perform fundamental research on electronics and computers.) The U.S. government has concentrated on developing military applications and supporting research at universities. Japanese industry is able to finance high levels of its own R&D, but with the aid of government programs that emphasize high risk R&D requiring large amounts of capital and supported by government programs in fundamental research. Because of the relatively weak positions of their computer and electronics industries, the European governments have provided extensive support for technology development in an effort to make their industries competitive with the United States and Japan. (Appendix III has more information on government efforts to develop electronics.)

U.S. government funding for three electronics technologies

Your February 8, 1983, letter requested information on the amount of R&D that the U.S. government supports or funds in three electronics areas that the Japanese government has identified as very important to future industries--super-lattice devices, three-dimensional circuit cells, and devices with high resistance to heat and nuclear radiation. (See the glossary for descriptions of these terms.) In 1983 the U.S. government spent approximately $34.7 million on these devices, while the Japanese government spent about $5 million. Because the U.S. effort is mainly defense-oriented (over 95 percent), it is not strictly comparable to the Japanese effort. As noted earlier, it is difficult to assess the commercial value of defense R&D. More information on U.S. government funding in these areas is included in appendix V.

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[4] The European Community is an organization made up of 10 countries, including West Germany, France, and the United Kingdom. It is also called the European Economic Community and the Common Market.

GOVERNMENT PROGRAMS TO DEVELOP MATERIALS TECHNOLOGY[5]

Materials technology and materials science are important in all the leading industrialized societies. R&D interests in materials move quickly across national frontiers, and nearly the same problems and same opportunities are perceived around the world. As part of broader materials development efforts, all five governments are supporting research in ceramics, composite materials, polymers, and rapid solidification metallurgy--areas identified by studies worldwide as those likely to grow quickly in importance.

As in electronics, materials technology development programs reflect the different ways the five governments are organized to support R&D. Each government has focused on specific aspects of materials research, so there are differences in emphasis among the countries. The United States, for example, heavily supports the development of composite materials, while the West German government emphasizes research on polymers. (Appendix IV describes each government's efforts to develop materials technology.)

U.S. government funding for six materials technologies

The U.S. government supported $191 million in R&D in 1983 in the areas of composite materials, ceramics, crystalline polymers, conductive polymers, high-efficiency polymeric separation membranes, and advanced metals technology involving high-performance alloys. About 65 percent of the U.S. government support is for defense research, chiefly in composite materials. (Appendix V details information on U.S. government funding in these areas.)

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[5] As explained in appendix VII, material for this section was provided to us by the Office of Naval Research.

GOVERNMENTAL POLICIES INFLUENCING PRIVATE SECTOR RESEARCH AND DEVELOPMENT

In addition to providing funds for R&D, governments can affect technology development by influencing R&D in private industry. Taxes, antitrust provisions, incentives for capital investment, patent legislation, and regulatory activities can affect private sector R&D. We therefore surveyed published material and obtained information on these policies and relevant statutory provisions for the United States, Japan, West Germany, France, and the United Kingdom. It is often very difficult to measure the effect of governmental policies, such as taxes, on private sector R&D because individual policies are only one factor influencing industrial decisions. We were not able to identify published material that described or analyzed the effect of each statute's implementation in the different countries.

All five countries have tax provisions that affect private sector R&D, for the most part encouraging it. Tax provisions in the five countries are similar, but the United States has a few provisions not shared by the other countries, including tax advantages for small business investment companies that provide equity capital to small businesses, and a provision for regulated investment companies that provide funds to firms chiefly involved in developing new products or processes.

Each country identifies agreements among competing firms as an area of antitrust concern, but also considers how their provisions might affect the public interest. Joint ventures having possible anticompetitive effects are permitted if these effects appear to be outweighed by their benefits.

Government incentives for private capital investment can encourage R&D by making money available to start new, innovative firms or expand older ones. All governments have ways to encourage private capital investment, but they take different forms. The U.S. government provides incentives to create venture capital companies that provide financing to firms performing R&D. In 1982 the government also started the Small Business Innovation Research Program, which supports research projects in small businesses to help them attract private capital. The West German and French governments focus on loan subsidies and guarantees because firms tend to raise capital investment by borrowing rather than by selling stock. The Japanese government assumes the default risk for some new ventures by providing partial financing, thereby inducing private lenders to participate. The United Kingdom provides assistance in several ways, but has been reducing its programs.

All five governments grant patents, but there are some differences. All countries except the United States require holders to make use of the patent and provide for compulsory licensing. In addition, all countries except the United States permit third parties to comment on inventions through formal opposition proceedings.

Regulatory policies can affect R&D activity in areas like environmental protection, worker health and safety, health and safety standard for consumer products, rate-of-return regulation of public utilities, and the regulation of entry and market behavior of firms in certain industrial sectors such as transportation. Such regulations could have some possible adverse effects on R&D. Comparing regulatory policies is very difficult and we did not include it in our survey. (Appendix VI has more information on how these government actions can influence private sector R&D.)

AGENCY AND OTHER COMMENTS

We obtained written comments from the Departments of Commerce, Defense, Energy, Interior, State, and the National Science Foundation. The Office of Science and Technology Policy and the National Aeronautics and Space Administration provided oral comments. The comments, which were generally concerned with specific data about the agencies' programs have been incorporated in the appendixes where appropriate. Eight experts in the areas of electronics and materials technology and government economic policies to support technology development commented on an earlier draft of this report. Embassy officials provided informal comments on material referring to their countries.

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As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time, we will send copies of this report to the Secretaries of Defense, State, Energy, Interior, and Commerce; the Administrator, National Aeronautics and Space Administration; the Director, National Science Foundation; and the Director, Office of Science and Technology Policy.

Sincerely yours,

F. Kevin Boland
for J. Dexter Peach
Director

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ABBREVIATIONS

AT&T	American Telephone and Telegraph Company
BOM	Bureau of Mines
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
ESPRIT	European Strategic Program of Research and Development in Information Technology
GAO	General Accounting Office
GNP	gross national product
HHS	Department of Health and Human Services
IBM	International Business Machines
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NIH	National Institutes of Health
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
R&D	research and development
SBIC	Small Business Investment Company
VHSIC	very high speed integrated circuit

GLOSSARY

Terms Related to Electronics Technology

ARTIFICIAL INTELLIGENCE	The use of computer systems to perform functions commonly associated with human intelligence, such as problem-solving, logical reasoning, learning, and use of languages.
COMPUTER	A device that can accept information, apply prescribed processes to it, and produce new information; usually consisting of input and output devices, storage, arithmetic and logical units, and a central processing unit.
Computer-aided design	The use of computer as a tool assisting design for industrial, statistical, or other applications. Visual input and output devices are frequently part of the system.
Computer architecture	The way elements of a computer are interconnected to perform computational functions.
Computer hardware	The physical elements and interfaces in the computer, including electric, electronic, and mechanical equipment.
Computer software	The operating instructions which program or sequence the functioning of the computer hardware.
ELECTRO-OPTICAL DEVICES	Equipment that processes information through the use of both light and electricity.
Fiber optics	The use of fibers, such as mono-filament glass, to conduct optical signals. Fiber optics can replace metal conductors in many applications because of their smaller size, their nonconduction of electricity, their low level of radiation, and their resistance to corrosion.
Optical signal processing	The processing of light signals through the use of optics (in contrast to the processing of electric signals through electronic devices).

EXPERT SYSTEMS	Computer programs that perform specialized, usually difficult, professional tasks at the level of (or sometimes beyond the level of) human experts. Because their functioning relies so heavily on large bodies of knowledge, expert systems are sometimes known as knowledge-based systems. Since they are often used to assist the human expert, they are also known as intelligent assistants.
FIFTH GENERATION COMPUTERS	Computers anticipated in the early 1990's that will have major differences in design and capability from those currently in use, including the use of large-scale integrated circuits, parallel processing, and the ability to process information by inference.
INFORMATION SYSTEM	Interconnected computers or other devices for processing information.
INFORMATION TECHNOLOGY	The means--including computers and telecommunications--for acquiring, processing, storing, and disseminating vocal, pictorial, textual, and numerical information.
INTEGRATED CIRCUIT	A combination of interconnected elements inseparably associated on or within a continuous substrate to perform an electronic function.
Very large-scale integrated circuits	Integrated circuits containing up to 20 times as many electronic devices as those now in production.
MICROELECTRONICS	The technology of constructing circuits and devices in extremely small packages chiefly through integrated circuits.
NATURAL LANGUAGE PROCESSING	The processing of natural (human) language (e.g., English) by a computer to facilitate communication with the computer, or for other purposes, such as language translation.
SEMICONDUCTOR DEVICES	Electronic devices whose functioning part is a solid crystalline material whose conductivity is intermediate between that of metal and an electrical insulator.

SUPER-LATTICE DEVICES	Electronic devices made with two semi-conducting materials with different properties that are interleaved in thin layers to create better electronic properties, such as higher-speed operation.
THREE-DIMENSIONAL INTEGRATED CIRCUITS	Integrated circuits constructed by alternately stacking layers of active elements and insulation. Most current integrated circuits have one layer of active elements and one layer of insulation.

Terms Related to Materials Technology

CERAMICS	The art and science of making solid articles that are composed primarily of inorganic, nonmetallic materials. While the term was once applied to pottery, porcelain, refractories, and clay products made primarily from compounds of silicon and alumina, modern-day usage includes production of parts for high-technology applications using boron carbide, silicon carbide, silicon nitride, beryllium oxide, and magnesium oxide (often in combination with other oxides), nonmetallic magnetic materials, ferroelectrics, glass ceramics, and manufactured single crystals.
COMPOSITE MATERIALS	Structural materials made by combining a matrix material and reinforcing fibers or particulate filler. Some composites are hybrids of two types of fibers within a single matrix. Common matrices are epoxies, polyesters, and aluminum. Fibers include graphite and glass; particulate matter consists of mica, carbon black, silica, silicon carbide, etc.
Carbon/carbon composites	Produced by pyrolyzing a graphite/organic matrix composite. This process achieves graphitization of the matrix so that the result is a composite of graphite fibers within a graphite structure (i.e., carbon fibers within a carbon matrix).
Metal matrix composites	Composites in which the matrix is a metal. Examples are aluminum reinforced with boron fibers, boron/titanium, graphite/aluminum, graphite/magnesium, beryllium/titanium, and superalloys reinforced with refractory metal or oxide filaments.

Organic matrix composites	Composites in which the matrix is made from organic polymeric materials. Generally, thermosetting resins such as epoxies are used for structural applications where rigidity is required, but thermoplastic polymers are also reinforced depending upon the application.
Materials science and engineering	The study and application of knowledge about how the composition, structure, and processing of materials affects their properties and uses.

METAL

Amorphous metals	Metals possessing no long-range structural periodicity (i.e., those that are noncrystalline). They are placed in that state by cooling very rapidly from the melt, thus preventing nucleation of the crystalline state. Amorphous metals can have special magnetic and mechanical properties and frequently are more resistive to corrosion.
Powder metallurgy	The process of producing metal powders and of using such powders in the production of solid components and shaped objects. The use of powder metallurgy parts often results in reduced costs since complex shapes can be made directly to size without further machining or fabrication. Metals that are difficult to melt, cast, and fabricate are often produced by powder metallurgy.
Rapid solidification metallurgy	Application of high cooling rates during solidification of metals, which can result in microstructural and property improvements unattainable with conventional solidification. Cooling rates can vary from 10^2 to 10^9°K per second, depending on the process and material, in contrast to normal cooling rates of less than 10°K per second.
Microcrystalline alloys	Alloys that have a very fine grain size and attendant improvement in mechanical properties. Such alloys are often produced by consolidation of fine powders produced by rapid solidification from the melt.

POLYMERS	Long chain molecules of appreciable molecular weight (generally in excess of 10,000) built up from simple molecules. High polymers (macromolecules) can be either organic, inorganic, or a hybrid of both. Polymers are either naturally occurring (cellulose, silk, etc.) or synthetic (polystyrene, nylon, orlon, etc.).
Conducting polymers	Polymers that conduct electricity. The only known polymer that inherently conducts electricity is sulfur nitride $(SN)_x$. Other polymers, normally insulating, are made conductive by doping with small amounts of chemical impurities (also called plastic metals or synmetals). Their conductivities are less than those of metals such as copper and aluminum, but some are superconducting, and have no resistance to current flow at the appropriate conducting temperature.
Crystalline polymers	Polymers that have the ability to crystallize because of their regularity in chemical composition and configuration. Examples are Nylon 66, linear polyethylene, and isotactic polypropylene. Polymers are generally polycrystalline; that is, they contain both amorphous and crystalline regions.

INVESTMENTS IN SCIENCE
AND TECHNOLOGY IN EACH COUNTRY

The United States, Japan, West Germany, France, and the United Kingdom all make major investments in research and development (R&D) in comparison to other countries. Together, the five countries perform about 85 percent of all R&D by the 24 members of the Organization for Economic Cooperation and Development (OECD). The members of OECD perform almost all R&D by non-Communist countries.

Although Japan and West Germany have increased R&D spending faster than the United States in the past, the latest data show that the United States still spends more on R&D than the other four countries combined. However, Japan and West Germany now spend about the same proportion of their gross national product (GNP) on R&D as the United States, and spend a higher proportion of their GNP on nonmilitary R&D than the United States. The United States employs the largest number of scientists and engineers in R&D, both in absolute numbers and as a proportion of its total work force. However, over the last 15 years, Japan and West Germany have greatly increased the proportion of their workers engaged in R&D.

Countries differ in the definitions they use and in their data collection and reporting practices, but the OECD and the U.S. National Science Foundation (NSF) have worked to develop comparable data on the five countries. Most of the information in this appendix is from these sources. Specific sources are indicated in the text.

NATIONAL EXPENDITURES FOR RESEARCH AND DEVELOPMENT

As the following table shows, the United States has larger overall R&D expenditures (including government, university, and private industry spending) than the other four countries combined.

Table I-1
National Expenditures for Research and Development
(billions of U.S. dollars)[a]

Country	1969	Percent	1975	Percent	1979	Percent	1981	Percent
United States	$25.6	62	$35.2	54	$ 54.9	54	$ 72.1	53
Japan	4.7	11	11.0	17	18.3	18	27.1	20
West Germany	3.9	9	7.7	12	12.6	12	15.8	12
France	3.2	8	5.3	8	8.0	8	10.9	8
United Kingdom	3.9	9	6.1	9	8.1[b]	8	11.3	8
Total	$41.3	100[c]	$65.3	100	$101.9	100	$137.2	100

[a] National expenditures converted into U.S. dollars using purchasing power parity exchange rates. Latest data available for all countries. (Dollar values not adjusted for inflation.)

[b] United Kingdom data is for 1978.

[c] Some percentages do not add, due to rounding.

Sources: National Science Foundation and Organization for Economic Cooperation and Development.

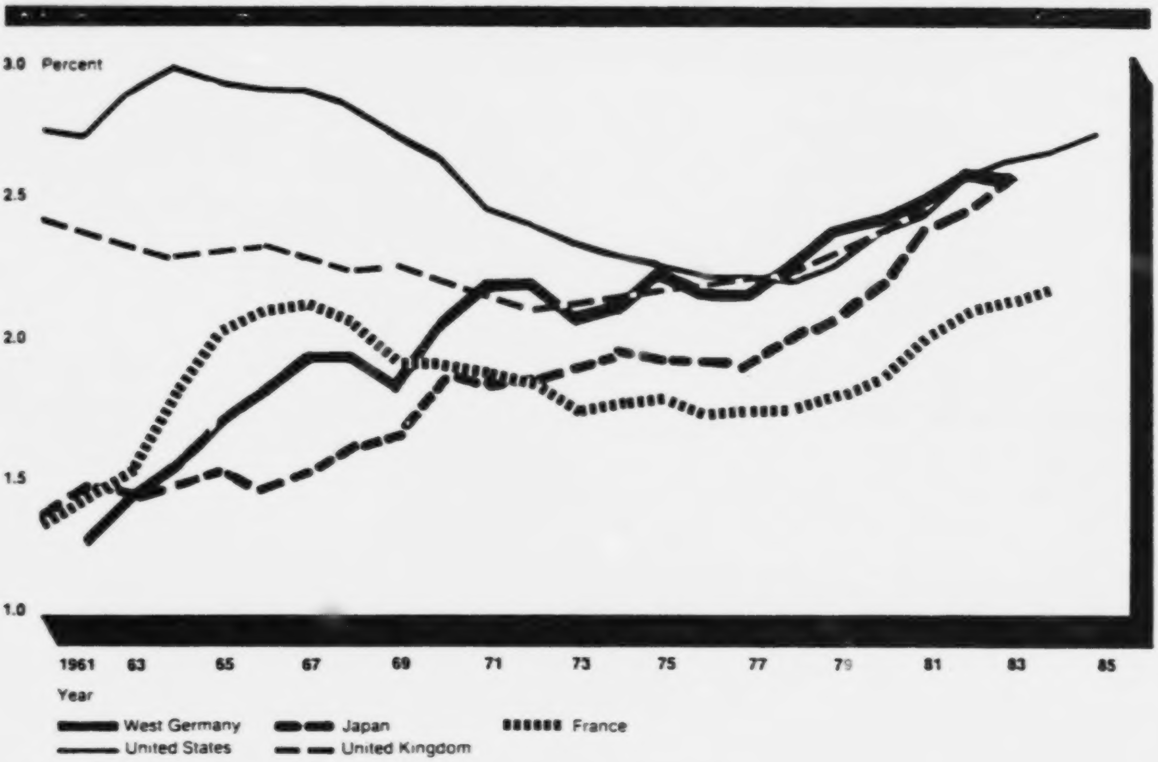
As shown in the preceding table, the U.S. share of total R&D among the five countries was about 62 percent in 1969 and has been over 50 percent since 1975. The change in the United States' position results largely from the growth of R&D expenditures in Japan and West Germany.

An examination of average annual growth rates of national R&D expenditures shows a 15-year trend of increased Japanese and West German R&D expenditures. From 1964 to 1970 the growth rate of the United States (in constant 1975 prices) was less than 2 percent, as compared with about 14 percent for Japan and about 10 percent for France, between 1963 and 1969. During the early 1970's the U.S. growth rate fell to 0.5 percent compared with about 12 percent for Japan, 8 percent for West Germany, and 2.2 percent for France. After 1973 however, the United States' growth rate increased to an average of 2 percent compared with 6 percent for Japan, 4 percent for West Germany, and 3 percent for France and the United Kingdom.

The proportion of a nation's resources devoted to R&D can be analyzed by looking at the ratio of R&D expenditures to the GNP. However, there are some limitations that limit comparison among countries over time on the use of data to compare the level of national R&D expenditures. One limitation is that inflation may have a greater impact on industrial R&D than on the general economy. A second is that the composition of economies can change over time. Differences in productivity also limit comparisons. Chart I-1 shows trends in R&D as a proportion of the GNP.

Chart I-1

National Expenditures For Performance of Research and Development
As a Percentage of Gross National Product by Country: 1961-85



Note: The latest data (1980-1985) may be preliminary or estimated. Missing years not available.

Source: National Science Foundation, International Science and Technology Data Update, Jan. 1985.

The United States' ratio was almost 3 percent in 1964. After a period of decline through the early to mid-1970's, the ratio began rising again in the late 1970's and is estimated to be 2.6 percent in 1984. All other countries had similar patterns of leveling off in the mid-1970's, with growth beginning in the late 1970's. Up to the mid-1970's, Japan increased its investments in R&D at a very fast rate the size of its economy. After a decline, the R&D-to-GNP ratio showed another increase in 1978, reaching about 2.6 percent in 1983.

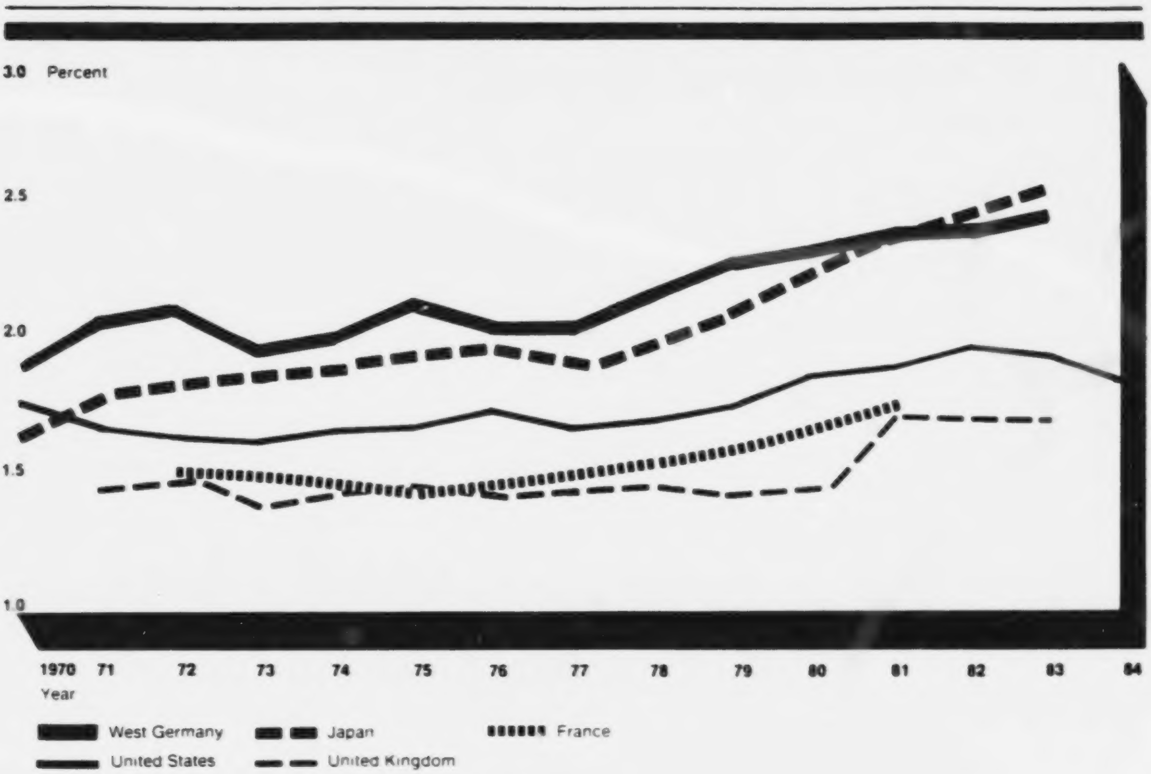
West Germany shows the most dramatic R&D-to-GNP increase. In the period 1962-71, the ratio sharply increased. In the late 1970's West Germany devoted a larger portion of its GNP to R&D than the other four countries. In 1983, the United States, Japan, and West Germany all devoted about 2.6 percent of GNP to R&D.

NONDEFENSE RESEARCH AND DEVELOPMENT EXPENDITURES

The National Science Foundation defines nondefense R&D expenditures as all publicly funded nondefense R&D as well as all privately funded R&D. Although defense R&D may have important economic spin-offs, nondefense R&D is more closely linked to economic goals. Chart I-2 compares civilian R&D expenditures among countries between 1970 and 1984.

Chart I-2

Nondefense R&D Expenditures[a] as a Percentage Of Gross National Product By Country: 1970-84



[a] National expenditures for R&D excluding government funds for defense.

Note: Missing years not available.

Source: National Science Foundation, International Science and Technology Data Update, Jan 1985.

Since 1970 Japan and West Germany have had the highest percentages of GNP devoted to national civilian R&D expenditure and have continued to increase their investments. In 1983 investments in nondefense R&D reached 2.5 percent for West Germany and 2.6 percent for Japan compared with 1.9 percent for the United States. The U.S. civilian-military funding balance has shifted. Defense R&D represented 66 percent of all government-sponsored R&D in 1984, compared with 51 percent in 1981.

Although the United States has a lower nondefense R&D-to-GNP ratio than do Japan and West Germany, the United States outspends the other nations in nondefense R&D. After a period of stability in the mid-1970's, the United States' ratio began a growth period in the late 1970's, with increased federal government funding in the energy, environmental, and health areas.

RESEARCH AND DEVELOPMENT BY INDUSTRY

Table I-2 shows the percentage of R&D investments financed by private industry. The table shows a general balance of responsibility for funding R&D between government and private industry for all countries except Japan. These countries show a slight trend in increased industry funding, especially in the United States. In Japan, however, industry has contributed more financing--64 percent of all R&D expenditures in 1983.

Table I-2

Percentage of National Research and Development Expenditures from Private Industry Sources: 1970, 1979, 1983

Country	1970	1979	1983
United States	38	46	50
Japan	59	59	64
West Germany	53	55	58
France	37	44	42
United Kingdom	42	43	41[a]

[a] Latest data for the United Kingdom are from 1981.

Note: Most of the remaining nonprivate funding of R&D is from government funding.

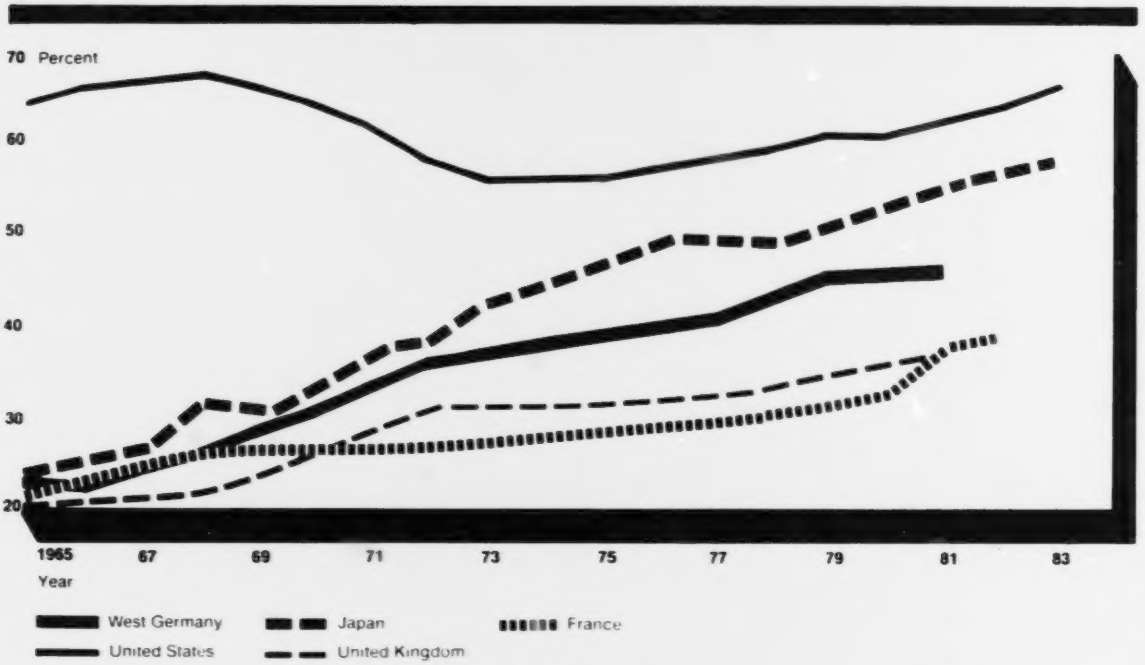
Sources: National Science Foundation, International Science and Technology Data Update, January 1984 and January 1985.

THE SCIENTIFIC AND TECHNOLOGICAL WORK FORCE

Chart I-3 shows the number of scientists and engineers engaged in R&D as a proportion of the total work force population. The United States has a higher proportion of R&D scientists and engineers in the labor force than any of the other four countries.

Chart I-3

Scientists and Engineers[a] Engaged in Research and Development Per 10,000 Labor Force Population by Country: 1965-1983



[a] Includes all scientists and engineers engaged in R&D on a full-time-equivalent basis (except for Japan, whose data include persons primarily employed in R&D, excluding social scientists, and the United Kingdom, whose data include only the government and industry sectors)

Note: Estimates are shown for most countries for latest years. Missing years not available.

Source: National Science Foundation, International Science and Technology Data Update, January 1985.

From the late 1960's to the mid-1970's, the U.S. ratio of scientists and engineers engaged in R&D per 10,000 of the labor force decreased while the ratio increased in the other countries. This shift was due to a drop in the number of U.S. scientists and engineers engaged in R&D as well as more rapid increases in each of the other countries. Since the mid-1970's, the U.S. ratio has been rising along with the other four countries.

The number of scientists and engineers engaged in R&D is higher in the United States than in the other four countries--about 750,000 in 1983. In 1981, the United States had more scientists and engineers engaged in R&D than Japan, West Germany, France, and the United Kingdom combined.

Data on educational degrees awarded in scientific and technological areas show how each country is adding to its labor force. In table 3 we indicate the number of first degrees awarded by universities and colleges. (First degrees are bachelor's degrees or their equivalents.) Differences among countries in degree requirements and in definitions create some uncertainty in comparing data on degrees awarded.

Table I-3
Number of First University Degrees[a]

	United States (1982)	Japan (1982)	West Germany (1982)	United Kingdom (1982)	France (1980)
	(thousands)				
Natural Sciences	102	12	8	17	10
Engineering	68	74	7[b]	10	12
Social Science	113	158	15	19	12
All other degrees	754	139	21	20	19
Total	1,037	383	51	66	53

[a] Data are estimated due to differences in degree requirements and definition. (First engineering degrees are master's degrees.)

[b] Does not include about 16,000 engineering graduates from 3-year programs in technical colleges.

Sources: National Science Foundation, International Science and Technology Data Update, January 1985 and unpublished data.

One of the major differences among the five countries is the varying emphasis placed on engineering degrees. Japan graduates more engineers than the other four countries. In 1982 over 19 percent of all graduates in Japan received engineering degrees as compared with 7 percent of all U.S. graduates with engineering degrees. In 1982 about 14 percent of all bachelor's degrees in West Germany were granted to engineers; in the United Kingdom the share was 17 percent; and in France it was about 23 percent.

Countries also vary in the proportion of degrees awarded in the fields of natural science and engineering combined. The proportion is about 16 percent in the United States, compared with 22 percent in Japan, 30 percent in West Germany, and about 41 percent in France and the United Kingdom.

The number of United States' graduates per year in the natural sciences and engineering fields (about 170,000) is much larger than the Japanese total (about 85,000). Additionally, the United States graduates more students in these science and engineering fields than the other countries combined. The United States graduates the most natural scientists at the first university degree level as a proportion of population, while Japan graduates the most engineers.

Table I-4
Number of First University Degrees in the Natural Sciences and Engineering per 100,000 Population

Country	Natural Science	Engineering
United States	43.4	29.0
Japan	10.0	62.1
United Kingdom	30.9	18.8
West Germany[a]	13.2	11.6
France[b]	12.8	21.9

[a] If engineering graduates from Fachhochschulen (3-year technical colleges) were included, the engineering ratio would be 36.2.

[b] First engineering degrees in France are master's degrees. Data on natural science degrees is for 1980.

Source: National Science Foundation, International Science and Technology Update, Jan. 1985.

The United States produces a much greater number of doctoral-level natural scientists and engineers than do Japan or West Germany in terms of total number and in proportion of total degrees. In 1982 the United States produced over 13,000 doctorates in the natural sciences and engineering; West Germany produced 3,700 in 1980; and Japan produced about 2,000 in 1981. The proportion of science and engineering doctorates granted in the United States to foreign citizens was 22 percent in 1981 and 23 percent in 1982. In engineering alone, foreign citizens constituted more than one-half of the graduating doctorates. Although there are no data on how many of these foreign engineering students actually stay to work in the United States, many plan to remain.

ORGANIZATION FOR SCIENCE AND TECHNOLOGY IN EACH GOVERNMENT

The United States, Japan, West Germany, France, and the United Kingdom all have a wide range of R&D activities and hope to advance in practically all fields of knowledge. All five have major flows of funds between government and private enterprise for R&D.

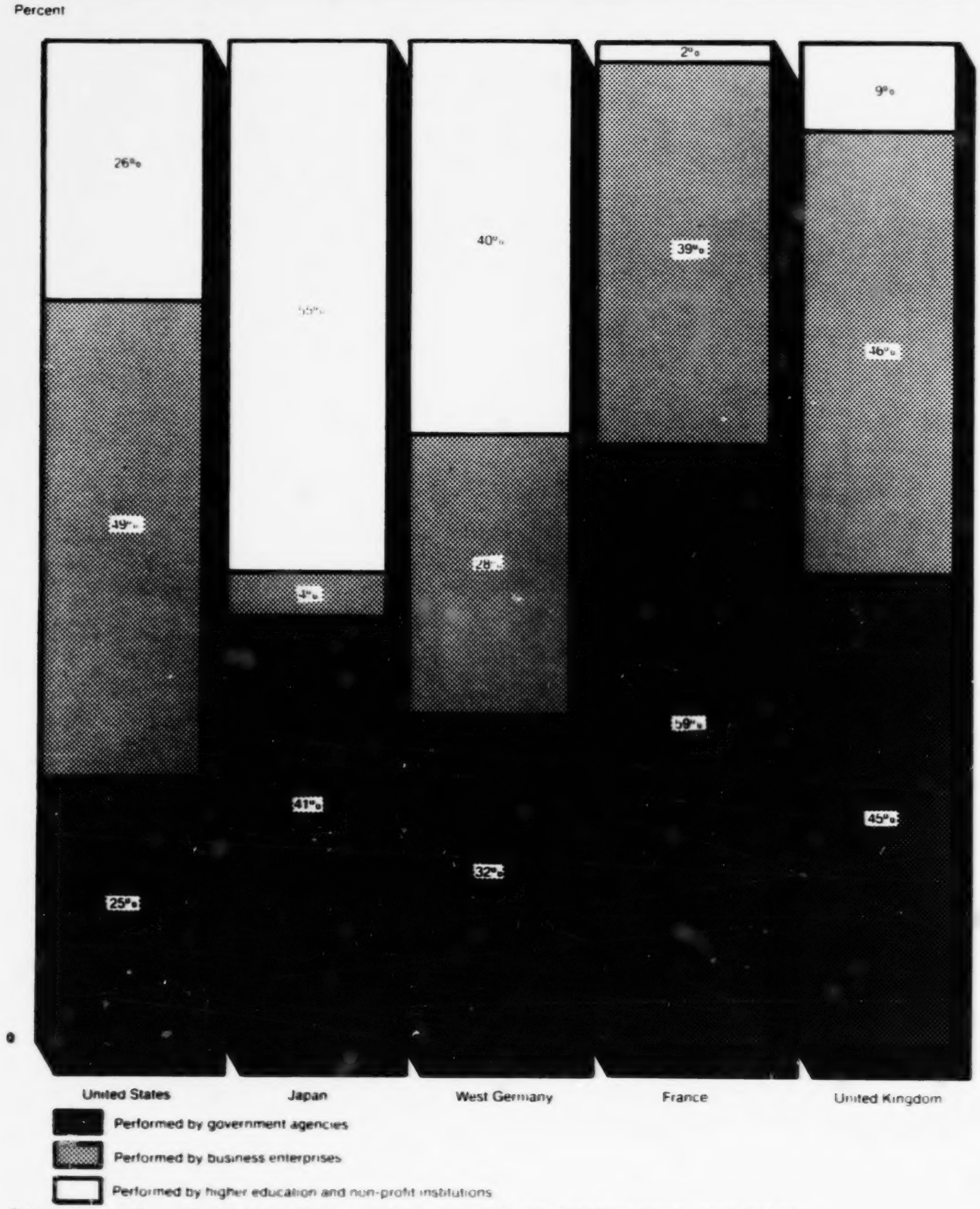
The following table shows that there are both similarities and differences in how each government allocates funds among government agencies, business enterprises, and universities and nonprofit institutions for R&D. Business enterprises, universities, and nonprofit institutions perform about 75 percent of government-funded R&D in the United States and about 41 percent in France; the other countries' R&D fall within this range.

In comparison to the other four countries, the Japanese government makes relatively little use of business enterprises in performing R&D.

Chart II-1

Use of Government Funds for Research and Development

(percentage of all government research and development funds-1981)



Sources: National Science Foundation and Organization for Economic Cooperation and Development, unpublished data

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[a] Data from United Kingdom are for 1978.

Table II-1 shows that the governments also differ in the proportion of their R&D funds spent for specific purposes. The governments of the United States, France, and the United Kingdom have large defense R&D expenditures, while those of Japan and West Germany do not. Japan, in many respects, and West Germany, to a lesser degree, are restrained by post-World War II arrangements from maintaining massive strategic and conventional defense structures. The governments also differ in the proportion of R&D funding spent on energy, civil space, industrial development, health, and agriculture.

Table II-1
Purpose of Public Research and Development Expenditures - 1981

Purpose	United States	Japan	West Germany	France	United Kingdom
	(percent)				
Defense	56.8	5.1	15.4	50.7	67.5
Energy	10.8	26.2	26.4	9.5	7.9
Civil space	9.6	12.2	7.2	5.4	2.7
Industrial development	.3	12.5	18.9	11.3	9.7
Health	12.4	5.5	7.1	5.7	1.6
Agriculture	2.6	25.3	3.4	5.1	5.7
Other	7.4	13.2	21.6	12.3	4.9
Total	100[b]	100	100	100	100

[a] Funds for advancement of knowledge category are excluded because of the lack of comparability amoung countries. In 1981 advancement of knowledge constituted 52.3 percent of government funds in Japan, 42.3 percent in West Germany, 24.1 percent in France, 26.6 percent in the United Kingdom, and 4 percent in the United States.

[b] Totals do not add due to rounding.

Source: Organization for Economic Cooperation and Development, unpublished data.

The following sections of this appendix describe how the governments are organized to manage and support R&D. For each government, we identify the main R&D agencies, their functions, and their methods of supporting R&D in industries and universities.

UNITED STATES

During the 1970's, the Office of Science and Technology Policy and the Office of Technology Assessment were created to advise the President and the Congress, respectively, and to strengthen the government's ability to consider R&D issues as a whole. Responsibility for performing and funding R&D, however, remains distributed among several agencies. As the following table shows, five agencies support most of the government's R&D activity.

Table II-2

U.S. Government Support for Research and Development

Agency	1983 funds (billions)	Percentage of total
Department of Defense	$ 23.1	60
Department of Energy	4.6	12
Department of Health and Human Services	4.3	11
National Aeronautics and Space Administration	2.4	6
National Science Foundation	1.1	3
Other	3.2	8
Total	$ 38.7	100

The National Science Foundation provides general support for research at universities, while the four other agencies conduct research related to their specific function atgovernment laboratories, industry, and at universities. A description of the primary research performed at each agency follows:

--Department of Defense (DOD) programs are primarily for weapons development.

--The Department of Energy (DOE) develops nuclear weapons and performs research in high energy physics and energy technologies, nuclear physics, health and environmental sciences, basic energy sciences, and energy technologies.

--The Department of Health and Human Services (HHS) sponsors health-related research.

--The National Aeronautics and Space Administration (NASA) performs research for space exploration and aircraft technology.

Support for industry

Government policy is to support basic research while relying on industry to perform R&D for commercial products. There is no single agency with broad responsibility for supporting the development of technology for use by industry. However, there are some programs intended to support technological innovation in specific industries. For example, the Department of Agriculture develops agricultural technologies, NASA conducts research to advance aircraft technology, the Department of Energy develops energy technologies, and the Department of the Interior conducts R&D programs in support of the mining and mineral processing industries, as well as research on materials conservation, materials substitution, recycling and long-lasting materials. In addition, the National Bureau of Standards (NBS) conducts research useful to industry, primarily on methods of measurement and standardization.

Support for universities

Five agencies sponsor 92 percent of the federal government's support for university research, which was $4.5 billion in 1983. HHS provides 49 percent of the support, chiefly in the life sciences. NSF supplies 18 percent of the support across many academic disciplines. DOD supports 11 percent of the research, mostly in engineering, the physical sciences, mathematics, and computer science. The DOE provides 6 percent of the support, chiefly in the physical sciences. The Department of Agriculture, which also provides 6 percent of the government's support, focuses on the life sciences.

Except for the Department of Agriculture, agencies primarily support specific research projects. The federal government does not directly support general university operating costs, as is the case in some other countries.

JAPAN

Three agencies share broad responsibilities for science and technology activities in Japan. The Science and Technology Agency, which is responsible for about 27 percent of government R&D expenditures, has large research programs in space and nuclear energy as well as in more basic research. The Ministry of International Trade and Industry, which received about 13 percent of the government's R&D funds, focuses on industrial needs and energy development. The Ministry of Education, which supported about 47 percent of R&D activities in fiscal year 1985, is chiefly responsible for research at universities. Defense research accounts for 4 percent of government R&D spending.

R&D support for industry

The Ministry of International Trade and Industry performs R&D for technology innovation in industry. The Agency of Industrial Science and Technology, which is part of the Ministry, has 16 research institutes that perform research in many fields, including electronics, chemicals, polymers, textiles, and pollution. In addition, the Ministry promotes R&D in the private sector. The Ministry works closely with scholars and experts in many fields in performing and promoting R&D activities.

In addition to general research programs, the Ministry sponsors cooperative research projects with industry. For example, the Ministry is currently sponsoring a project to develop a high-speed computer for scientific purposes. This project, which involves six companies, is scheduled to last from fiscal year 1981 to fiscal year 1989.

In addition to the Ministry of International Trade and Industry, the Science and Technology Agency also performs research to support industrial development. For example, the Agency's National Institute for Research in Inorganic Materials performs basic ceramics research in cooperation with the Ministry of International Trade and Industry. The Agency also has an aerospace laboratory that has been working on a short-takeoff and landing aircraft since 1972, in the hope that the results of this program will lead to the development of a commercial aircraft in cooperation with Japanese industry.

Support for universities

Most government support of university research is supplied by the Ministry of Education. The Ministry provides all of the funds for national universities and national institutes that are centers of scientific research in Japan.

The university research is supported by the Ministry in three ways:

- --Universities receive research funds according to a formula based on the number of professors and other factors. Formula-based research grants were 90,743 million yen (about $390 million) in 1982.
- --Faculty members compete for research grants by submitting proposals, which are reviewed by panels of scientists. These grants totaled 38,000 million yen (about $163 million) in 1982.
- --University salaries, building facilities, and large-scale instrumentation are provided for by the Ministry.

WEST GERMANY

The Ministry of Research and Technology receives about 58 percent of the government's R&D funds. About half of the Ministry's budget funds research projects in industry. The remainder is used to support government research centers and independent research organizations. Other research agencies are the Ministry of Defense (14 percent of government R&D funds), the Ministry of Economics (10 percent), and the Ministry of Education and Science (8 percent).

Germany has 13 national research centers that specialize in different fields, including nuclear research, medicine, aerospace technical research, mathematics, and data processing. The Ministry of Research and Technology provides 90 percent of the money for their support, while Land (state) governments provide the other 10 percent.

There are two independent research organizations that get much of their funding from the government. The Max Planck Society, which is the largest research organization in Germany, consists of over 50 research institutes that specialize in different fields. The Society performs research that universities cannot undertake easily, such as interdisciplinary research and work in fields requiring specialized equipment or resources.

The Fraunhofer Gesellschaft has about 30 institutes that carry out applied research in the natural sciences and engineering. Some of the institutes work closely with industry, while others perform research for the Ministry of Defense.

Support for industry

The Ministry of Research and Technology supports most R&D, excluding defense. About half of the Ministry's funds are allocated to individual research projects, which are mostly performed by private industry. The rest of the Ministry's funds are used to support research organizations, such as the government's national research centers, the Max Planck Society, and the Fraunhofer Gesellschaft.

Support for universities

Most German universities are financed by the Land governments, which provide money for full-time staff and for operating costs. The German government provides some research support to universities through the German Research Society, a central organization for assisting fundamental research. The Society, which is a nongovernmental organization whose members include universities, independent research organizations, academies of science, and scientific associations, makes grants to scientists on the basis of their research proposals. The German government supplies about half of the Society's funding, with the remainder coming from the Land governments.

FRANCE

The Ministry of Research and Technology is responsible for most of the government's nondefense R&D. It is responsible for fundamental scientific research as well as research in nuclear energy, space, and other areas. The Ministry's 1983 R&D budget was 25.3 billion francs (about $3 billion).

In addition to managing governmental research programs, the Ministry is also responsible for nationalized industries owned by the government. About 32 percent of all industry is under governmental control, including 60 percent of electronics and information processing, 54 percent of basic chemicals, 75 percent of armaments, and 80 percent of iron and steel. Nationalized components perform nearly half of all industrial R&D.

Defense receives 40 percent of government R&D funds. Most of the work is performed by industry.

Support for industry

The Ministry of Research and Technology, the main government agency supporting technological innovation in industry, supports technological innovation in several ways. Within the Ministry, the National Agency for the Implementation of Research provides subsidies and loans to help industry implement research results. The Data Processing Agency collaborates with research laboratories, users, and industry to determine new data processing applications. The National Institute for Computer Sciences and Automation Research performs research in data processing and automation.

The government has developed long-term plans to guide the overall development of industrial sectors, with heavy emphasis on technological development. For example, in 1982 the government announced a plan for the electronics sector, which proposed spending 140 billion francs (about $26 billion) over 5 years, and selected nine parts of the electronics industry for development. The plan's cost covers public and private investment, training, and education, as well as R&D activities.

Support for universities

The government supports university research largely through the National Center of Scientific Research, which is part of the Ministry of Research and Technology and had a 1984 budget of 7.5 billion francs (about $942 million). The Center has its own research facilities, but a substantial part of its program is contracted out to associated laboratories and research teams, mainly at universities. The Center directly operates 350 laboratories and research teams and cooperates with universities and other organizations to operate 850 others.

UNITED KINGDOM

The Department of Education and Science and the Department of Trade and Industry each have broad responsibility for the government's nondefense R&D activities. The Department of Education and Science, which supports university research and other research establishments, performed about 27 percent of the government's R&D activities in 1982. The Department of Trade and Industry manages government laboratories and supports R&D in private industry. It was responsible for about 8 percent of the government's R&D in 1982.

Defense programs, managed by the Ministry of Defense, make up about 50 percent of all government R&D activity. The Ministry of Defense has its own research establishments and contracts with industry. It provides less than 2 percent of the financial support for basic scientific research at universities.

Support for industry

The Department of Trade and Industry supports R&D to increase technological innovation in industry. About 61 percent of the Department's 1983 expenditures for R&D was spent by industry and research associations. The Department supports projects from the early stages of R&D to the design, development, and introduction of new products. Support is provided through grants for eligible project costs, shared-cost contracts, and the purchase of pre-production models for loan to potential customers.

About 33 percent of the Department's funds are for its laboratories and other government departments. Departmental research laboratories help develop measurement and specification standards, perform research to explore new fields, enhance mature technologies, and provide specialized expertise and facilities for industry.

The government enourages technological innovation in industry by investing in private companies. It provides capital and loan guarantees to a computer company and finances a company that produces electronic devices. The Department of Energy supports research related to the energy industries.

Support for universities

The United Kingdom government provides most university funding. The Department of Education and Science administers most governmental support for university research. Funding is provided in two ways. Money for individual research projects is provided through five research councils, and overhead costs such as office space and equipment are funded through the University Grants Committee.

There are research councils for five areas: science and engineering, medical research, environment, agriculture, and social science. In 1983, the research councils supported about 155 million pounds (about $225 million) in university research, including postgraduate awards. The research councils review proposals from university scientists and award research grants. They also directly operate research establishments. The four laboratories of the Science and Engineering Research Council are operated as facilities where university faculty members can perform research in capital-intensive subjects. The 1983 operating cost of these laboratories was about 78 million pounds (about $114 million).

The University Grants Committee estimates that its 1983 contribution to university R&D activity was 563 million pounds (about $817 million).

EUROPEAN COMMUNITY

The European Community is an organization made up of 10 countries, including West Germany, France, and the United Kingdom. The Community is designed to permit free movement of goods, persons, services, and capital among member countries as well as to establish common foreign trade, agriculture, and transport policies.

The Community has its own laboratory facilities and also funds research in member countries. The four major areas of research are security of the supply of natural resources, promotion of internationally competitive industry, improvement of living and working conditions, and protection of the environment.

GOVERNMENT PROGRAMS TO DEVELOP ELECTRONICS TECHNOLOGY

Modern electronics technology is based on integrated circuits, which incorporate many electronic devices on a small piece of material, usually silicon. Better integrated circuits have been the key to rapid improvements in computers and other aspects of information processing. These improvements have had a great impact on business and financial management, communications, military weapons, manufacturing, and consumer products.

Each government has supported electronics technology since the 1960's, particularly for use in computers. Since 1981, all five governments have announced new spending plans to advance electronics technology. These new plans involve the development and application of advanced electronic components, such as very large scale integrated circuits. Very large scale integrated circuits[1] will have higher performance levels and lower costs than those circuits now in use. Governments plan to use very large scale integrated circuits to advance computer capability for purposes such as artificial intelligence, computer-aided design and manufacturing, robotics, and large-scale scientific computation.

Governments differ in specific goals for their electronics programs and organizational approach, and in the role of defense programs. Several consultants who reviewed our report noted that it is very difficult to compare large, defense-related efforts in the United States with civilian-oriented efforts in other countries. Defense R&D is not directed toward commercialization. Defense expenditures may contribute to commercial technology in a spin-off effect, but the extent to which this occurs has not been measured.

The U.S. government is emphasizing electronics technology for military applications; the Japanese government is concentrating on long-term, large-scale electronics development projects for high-speed scientific computing, artificial intelligence and other related applications; and the three European governments are trying to overcome the current commercial advantage of the U.S. and Japanese electronics and computer industries. The three European countries are also taking part in a European community program to help member countries compete against U.S. and Japanese industry.

Governments differ in their approach to developing electronics technology. For example, Japanese projects are managed by industrial research associations, while French technology is developed by government-owned industries. Electronics technology is a high research priority for defense agencies in the United States, France, and the United Kingdom. Defense programs are of less importance in West Germany and Japan.

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[1] Definition of this and other technical terms are contained in the glossary.

U.S. and Japanese firms have been more successful than those in Europe in developing and marketing integrated circuits and computers. In 1982 U.S. firms had 61 percent of the world market for integrated circuits, the Japanese had 33 percent, and the Europeans had 6 percent. American computer manufacturers, particularly International Business Machines (IBM), have a large share of the European computer market and a smaller, but still significant, share of the Japanese market.

Government efforts to develop electronics technology reflect differences in the electronics and computer industries from among the countries. U.S. corporations dominated the early development of computers and integrated circuits and have been able to finance large amounts of R&D. The government has concentrated on developing military applications and supporting basic research. Japanese industry is also able to finance high levels of R&D, and government programs emphasize high-risk R&D requiring large amounts of capital. Because of the relatively weak positions of their computer and electronics industries, the European governments have provided extensive support for technology development in an effort to make their industries competitive with the United States and Japan.

UNITED STATES

U.S. industry dominated the early development of computers and integrated circuits and has been able to finance large amounts of R&D. By Department of Commerce estimates, U.S. industry spent about $2.5 billion for R&D on semiconducters and related devices worldwide in 1983. The National Science Foundation estimates that U.S. industry spent $5.1 billion on R&D in 1983 on office computing and accounting machines (almost all of the funding was for computers). Within the industry large research centers are maintained by IBM and the American Telephone and Telegraph Company (AT&T). Since 1982, U.S. computer and electronics companies have formed two associations to perform fundamental research--the Semiconductor Research Cooperative and the Microelectronics and Computer Technology Corporation. The U.S. government's Office of Science and Technology Policy has worked with the Department of Justice to facilitate the creation of these and other cooperative efforts.

We identified five agencies that support R&D in different aspects of electronics technology--DOD, NSF, NBS, NASA, and DOE.

Department of Defense

DOD was very influential in the early development of computers, semiconductors, and integrated circuits in the 1950's and 1960's. In 1983 it supported 80 percent of federally funded electrical engineering research and 56 percent of computer science research, two areas of science closely related to electronics technology. About 60 percent of university research in electrical engineering and computer science was supported by DOD. Within DOD, electronics research is managed by the staff of the Under Secretary for Defense, Research, and Engineering, the Defense Advanced Research Projects Agency, and the three military services--Army, Navy, and Air Force. In addition to the programs described below, DOD supports extensive electronic R&D as part of weapons development projects, but it would be very difficult to determine the extent of this electronics work.

Very high speed integrated circuit program (VHSIC)

DOD started the VHSIC program in fiscal year 1979 to develop integrated circuits for military purposes, primarily high-speed signal processing, in order to reduce the lag between the introduction of commercial integrated circuits and their use in military systems. The program is developing integrated circuits with electronic devices smaller than those now produced, which will withstand higher levels of radiation than commercially available circuits. DOD believes techniques developed in this program will be widely used to make better integrated circuits.

Most of this work is performed by large corporations under contract. The program is managed by the staff of the Under Secretary of Defense for Research and Engineering and had a 1984 funding level of about $125 million.

Strategic Computing Program

The Defense Advanced Research Projects Agency (DARPA) began the Strategic Computing Program in 1983 to develop a broad base of electronic and information technology for national security and economic growth. The program is planned to cost $600 million over 5 years. DARPA's 1984 budget called for expenditures of $50 million.

The program will include high-performance device technology, large-scale integrated systems, computer architecture, and artificial intelligence applications. Planned applications include a battle management system capable of extensive spoken interaction with people, a "pilot's associate" that can understand spoken commands and is small enough to put on an aircraft, and a vehicle that can "see" and move around without human guidance. The program will focus on seven technologies that need to be developed before these applications can be achieved, including

- --systems for codifying and mechanizing practical knowledge, common sense, and expert knowledge (expert systems);
- --improvement in speech recognition, vision, and natural language understanding (artificial intelligence);
- --ways to simplify and accelerate design and development of electronic systems;
- --new computer science theories;
- --ways to use parallel systems design in computers;
- --better ways to design electronic devices; and
- --better ways to fabricate electronic devices.

About 80 percent of the funds in the first 3 years of the program will be for basic technology and the creation of a program infrastructure (computing resources, design tools, standards development, and facilities for making prototype systems and integrated circuits).

Other DARPA research

DARPA conducts and sponsors research at federal laboratories, universities, and industry that is beyond the immediate requirements of the military services. The Electronics Sciences Division explores new concepts in electronic and optical materials. The Information Processing Techniques Office manages research on information processing and computer communications technologies.

Military service programs

Each of the three military services has substantial electronics programs, as shown in the following table. Programs of the three services are coordinated by the staff of the Under Secretary of Defense for Research and Engineering.

Table III-1

Electronics Research in the Military Services (FY 1984)

	Army	Navy	Air Force	Total
	- - - - - - - - ($ millions) - - - - - -			
Basic electronics research	$ 23.8	$ 28.3	$ 22.1	$ 74.2
Exploratory development of electron devices	22.5	30.1	22.8	75.4
Total	$ 46.3	$ 58.4	$ 44.9	$ 149.6

Electron device research in the three services is concentrated in microwave/millimeter wave devices, microelectronics, and electro-optical devices, with each of the services focusing on different aspects of each area.

National Science Foundation

NSF sponsors electronics research at universities. In 1984 NSF provided about $45 million for computer research, computer engineering, and solid-state and microstructures engineering.

The computer research program's objectives are to generate fundamental knowledge about the structure and design of computer systems, develop theories, and train researchers. Funding for this program was about $35 million in fiscal year 1984. NSF estimates that this program provides about 90 percent of all federal support for university research in theoretical computer science, 50 percent for university research in software systems science and software engineering, 33 percent for computer systems design, and 20 percent for intelligent systems. Most of the rest of the research support in these areas is provided by DOD.

The computer engineering program seeks to broaden the understanding of principles of design and construction of computers in areas like large-scale integrated circuits, the use of computers in designing computers, and the relationship between hardware and software in a computer. Funding was $3.7 million in fiscal year 1984. The computer engineering program is more hardware-oriented than the computer research program described above.

The solid-state and microstructures engineering program supports research on new electronic device concepts, new electronic materials, and advanced fabrication techniques in order to build smaller electronic devices. Funding for this program was $7.2 million in fiscal year 1984. As part of this program, NSF supports the National Research and Resource Facility for Submicron Structures at Cornell University, a research center intended for use by researchers in universities, industry, and government.

In addition to the above research, other NSF programs have some elements that are aimed toward aspects of electronics technology. For example, some of the materials research sponsored by NSF may contribute to the development of new electronic devices.

Department of Commerce
NBS

Two research organizations under NSB contribute to the development of electronics technology--the Center for Electronics and Electrical Engineering and the Institute for Computer Sciences and Technology. Both organizations work closely with other government agencies, private industry, trade associations, and standards-setting organizations. Research is directed toward developing new standards, measurement procedures, and technical information.

The Center for Electronics and Electrical Engineering performs R&D on measurement technology for electrical, electronic, and electromagnetic materials, components, instruments, and systems. The Center receives about $12 million a year in direct appropriations and also receives about $10 million from other federal agencies and calibration fees. The Center's work is divided into four program areas: electrosystems, electromagnetic fields, electromagnetic interface, fast-signal metrology, and semiconductor material process and device technology.

The Institute for Computer Science and Technology, which performs research, develops standards, and advises federal agencies on scientific and technological matters related to automated data processing (ADP), received about $10 million in directly appropriated funds in 1983 and reimbursement of $1.5 million from other agencies. The Institute develops test methods and standards for computer-based office systems, microprocessors, data management technology, data encryption, and other areas of computer technology.

National Aeronautics and Space Administration

NASA's electronics research program seeks to develop basic technology that can produce new concepts and devices for space missions. About half of the research is performed at NASA research centers and at the Jet Propulsion Laboratory, a government-owned facility operated by the California Institute of

Technology. NASA's 1984 funding level for electronics research was about $4.1 million. The three parts of NASA's electronics program are optical signal processing, quantum electronics, and solid-state research.

Department of Energy

Most DOE R&D electronics technology is for military purposes. The cost of research is about $30 million a year. Most research is performed in government-owned laboratories specializing in weapons work.

DOE also supports research in applied mathematics and computer science aimed at advancing fundamental knowledge about large scale scientific computational processes necessary for understanding the physical processes underlying many DOE R&D programs. This program cost about $15 million in fiscal year 1984 of which 60 percent was at DOE laboratories and 40 percent at universities. The research supports software engineering, design of parallel algorithms, architecture and software, and computational mathematics for large-scale scientific computing.

JAPAN

Six large, diversified companies dominate the Japanese computer and electronics industries. In 1983, Japanese industry spent about $1.4 billion in R&D in semiconductors and related development worldwide, according to U.S. Department of Commerce estimates. Commerce also estimates that the six leading Japanese firms spent about $800 million on computer-related R&D in the year ending March 31, 1983. The industry has been increasingly successful in developing computers and electronics. From 1976 to 1980, Japanese integrated circuit exports to Europe and the United States increased about 650 percent, to $465 million. In the 1980's the Japanese have been very successful in the development and production of some advanced integrated circuits. For example, in 1982 Japanese firms produced 66 percent of the most advanced dynamic random-access memory chip.

The Japanese government has been involved in the development of computers and electronics since the late 1950's, when a government laboratory developed experimental computers. During the 1960's, the government helped the computer industry in an effort to compete with U.S. manufacturers through market protection, tariffs, tax preferences, and other policies. However, during the 1970's, government policies changed to emphasize support for high risk R&D requiring large amounts of capital.[2]

Ministry of International Trade and Industry

The Ministry of International Trade and Industry supports cooperative research projects and also performs research in its own facilities.

Cooperative research with industry

The Ministry has developed and sponsored projects to expand technologies in the computer and electronics industries. From 1976 to 1982 Ministry support for cooperative projects averaged about $50 million per year. Several industrial firms participate in each of these projects, which last several years. Research is directed by associations that include all participating companies. There are currently several large computer and electronics projects.

Basic technology for electronic computers (fifth generation computer)

The Ministry initiated this project in 1982 to develop several computer systems for use in the 1990's. The project, which is regarded by the Ministry and outside observers as extremely ambitious, will span 10 years. Research objectives include computers that can translate language, serve as interactive reference libraries, and create computer software almost automatically.

The project is managed by the Institute for New Generation Computer Technology, a research foundation established in 1982. Eight manufacturers are participating. The government has not stated what the total project will cost, but estimates are about $500 million. However, there is uncertainty over whether the amount includes industry contributions.

The emergence of large-scale integrated circuits that substantially reduce hardware costs was a key factor for the Japanese in beginning the project. Project planners concluded that large-scale integrated circuits were necessary to avoid over-sized systems, and the project includes research on the design of these circuits. The project seeks to prepare basic artificial intelligence software and take advantage of artificial intelligence research achievements.

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[2] A more detailed description of these policies is contained in our reports Industrial Policy: Japan's Flexible Approach (GAO/ID-82-32, June 23, 1982) and Industrial Policy: Case Studies in the Japanese Experience (GAO/ID-83-11, Oct. 20, 1982).

High speed computer systems for scientific and technological uses (supercomputer)

This project, which began in 1981, is planned as a 9-year effort to develop a high-speed computer that can be used for scientific purposes. Research will be on two main subjects: (1) development of new high-speed logic and memory elements and (2) development of parallel processing systems.

The project is being carried out by the Electrotechnical Laboratory and the Scientific Computer Research Association, which was formed in 1981 by the six participating companies. The government will supply 23,000 million yen (about $105 million)[3] over the 9 years of the project.

Electronics research in the next generation industries basic technologies research and development program

In 1981 the government began a 10-year project to conduct long-term, high-risk, high-payoff research in electronics, biotechnology, and materials. The electronics portion of the project is directed by the Research and Development Association for Future Electron Devices, which was formed by the 10 participating companies.

Research is performed in three main areas. One area is the development of electronic devices for high-computation speeds at room temperature using super-lattice technologies. A second area is construction of multilayered electronic devices to increase the density of elements per chip. The third area is highly integrated circuits that resist heat and radiation. (U.S. funding for these three areas is discussed in appendix V.)

Optical measurement and control system

The Ministry started this project in 1979 to develop optical processing techniques. The project will continue until fiscal year 1985 and is projected to receive 15,700 million yen (about $72 million) from the Ministry. The research is being performed by nine companies at the Optoelectronics Joint Research Laboratory under the direction of the Engineering Research Association of Optoelectronics Applied Systems. The Laboratory is engaged in developing common basic technology, such as crystal growth and machine process technologies.

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[3] For specific government programs, we used the dollar conversion in the original source where available and used exchange rates published by the Department of Commerce when they were not. Conversion rates were used for the last quarter of the year stated.

The Electro-Technical Laboratory

The Electro-Technical Laboratory is a research facility within the Ministry that concentrates on electrical and electronics research. The laboratory built several experimental computers in the early and mid-1950's and has been involved in nearly every computer-related project sponsored by the Ministry. It had an annual budget of about $40 million in 1982.

Ministry of Education

Several universities supported by the Ministry of Education have electronics research programs. However, we have not found any information on the funding levels for electronics research. One study identified six universities with significant computer science and engineering programs.

Nippon Telegraph and Telephone Corporation

The corporation is owned by the government and performs electronics research related to telecommunications in four electrical communications laboratories. It performs advanced electronics research and works closely with industry in the development of new products and devices.

WEST GERMANY

The government has supported R&D in computers since 1967. From 1967 to 1979 West Germany gave 3.5 billion deutsche marks (about $2 billion) in aid to its computer industry, mostly in the form of R&D financing for its largest computer manufacturer. Information technology is now the government's highest research priority.

Ministry support for electronics research was 291 million deutsche marks (about $112 million) in 1984. The main emphasis of research is on the development of large-scale integrated circuits and on related problems. Other research areas include optoelectronic components, materials development, semiconductor manufacturing processes, and basic research. The Ministry is also supporting about 210 million deutsche marks (about $81 million) in R&D on data processing information technologies and telecommunications.

Starting in 1984 the government plans to spend 3 billion deutsche marks (about $1.1 billion) over 5 years for R&D in microelectronics, advanced computers, office automation, communication technology robotics, and other areas in an effort to compete with Japan and the United States. About $225 million will be spent on submicron technology, an important aspect of the development of large-scale integrated circuits, and $135 million on industrial automation.

The Max Planck Society, an independent research organization, receives government support for research in physics and science for integrated circuits. The Fraunhofer Gesellschaft, another independent research organization, receives government funds for applied research in the development and application of electronics. In addition to these independent research organizations, the government also supports university research.

German universities are working in a wide range of artificial intelligence areas, including expert systems, natural language, robotic vision, man-machine interface, deduction, and machine architecture. The government does not, however, have an overall plan for development of artificial intelligence like the Japanese Fifth Generation Computer Project.

In 1983 the Ministry of Research and Technology gave funds to a group of universities for research, development, and training in integrated circuit design. The program has 11 participating universities and will receive 100 million deutsche marks (about $39 million) over 3 years. In 1984 the Ministry started a program on knowledge-based systems. The German Research Society is beginning a long-range research program in artificial intelligence at two universities with a 1984 research budget of $37.5 million.

FRANCE

French government support of computer and electronics research is extensive and complex. In 1966 the government formed Compagnie International pour l'Informatique, the principal French computer company, as part of a plan to overcome U.S. leadership in European computer markets. Since then, the government has undertaken a series of plans to strengthen computers and electronics. In 1981 the government nationalized major electronics manufacturers and now owns 60 percent of the industry. Its goal is total French independence in electronics.

Five-year electronics plan

In 1982 the government began a 5-year electronics development program to improve the trade balance, create jobs, master the electronics field, and accelerate the growth of the electronics industry. Total investment in the electronics industry will be 140 billion francs (about $26 billion according to a U.S Department of Commerce estimate) over 5 years. This amount includes capital investments by the government and the private sector (including foreign-owned firms), as well as R&D.

Support for large, nationalized enterprises is the highest priority. The government supports one or two firms in each electronics sector to avoid competition among French firms because it believes the United States and Japan are the important competitors. R&D is concentrated in computer-aided design and manufacturing, software using artificial intelligence concepts, and three other areas.

The government's 5-year program followed the report of a major governmental task force that considered the situation of the French elecronics industry alarming because of a growing trade deficit and threats to French electronics strengths. The task force concluded that the government's forces were acting in a disjointed manner and that they must be gathered around a single global and strategic policy. It recommended that the government begin national projects, modeled on Japanese methods, that would bring together ongoing efforts and create bonds between research and industry.

In 1983 the government began five national projects in specific areas of the electronics industry: computer-aided design of large-scale integrated circuits, software engineering, computer-aided design and manufacturing; computer-aided translation, and graphics. The government estimated that it and the manufacturers together would invest 1 billion francs (about $125 million) in these projects over 4 years.

The component plan

In 1977 the government began a 5-year program to strengthen production of integrated circuits. The program supplied funds to five groups to produce the circuits. Program objectives were to win back the French integrated circuit market and attain independence in design. In 1982 the government extended the program through 1986. Public R&D funds for 1978-1982 were 600 million francs (about $110 million).

The Ministry of Research and Technology

In addition to the major programs described above, four units within the Ministry support development of electronics technology. Two agencies--the Data Processing Agency and the National Institute for Computer Sciences and Automation Research--are specifically involved in electronics technology. In addition, the National Center of Scientific Research supports fundamental research, including research related to electronics, and the National Agency for Implementation of Research finances research and its commercialization, including electronics technology.

The Data Processing Agency collaborates with research laboratories, users, and industry to determine new data processing applications, processes, and systems. In 1981 the Agency spent 100 million francs (about $17 million) on research, one-third of its total budget. Long-term research is performed by public and private research laboratories together with companies from the computer industry, while mid-term pilot projects bring together research organizations, industry, and the user community for 4 to 5 years.

The National Institute for Computer Sciences and Automation Research had an annual budget of 146 million francs (about $22 million) in 1982. Research has two objectives: research on computer science and automation and the development of experimental systems. There are eight research themes: numerical techniques and modeling, automation, images and robotics, algorithms and programming, languages and specifications, information systems, man-machine communications, and computer architecture.

A French study identified 15 university laboratories and teams associated with the National Center of Scientific Research that study electronics. Their 1982 R&D budget was 272 million francs (about $41 million).

The National Agency for Implementation of Research finances R&D projects and also helps industry develop commercial projects. The 1983 budget for the Agency was 900 million francs (about $108 million), which demonstrates that support of the electronics field is a high priority.

Ministry of Defense

Within the Ministry, the Directorate of Research, Studies, and Techniques finances fundamental research in computer science, semiconductors and components, quantum electronics, and other fields. Another directorate defines and implements industrial policy for production of electronic equipment. We were not able to obtain information on funding levels.

French National Telecommunications Research Center

The Center conducts research, exploratory development, and technical assistance in telecommunications. The Center has six laboratories, one of which specializes in microelectronics research. We were not able to obtain information on funding levels.

UNITED KINGDOM

The British government has supported the development of computers and electronics technology since the 1960's. The Ministry of Trade and Industry has several programs to support development of electronics technology. However, in 1983 the government decided that urgent steps were needed to improve the country's competitiveness in information technology. A study committee recommended a program for advanced information technology to achieve a positive trade balance in information technology by 1990 and preserve the current employment level in information technology in competition with the Japanese Fifth Generation computer project.

Program for Advanced Information Technology (Alvey Program)

The program, begun in 1983, is designed to develop four technologies regarded as key to the future development of information technology. These are

--very large scale integrated circuits to increase the performance and lower the cost of electronics in order to permit new applications;

--methods of computer programming that achieve efficient production, reliability, and economical development and operation;

--improvement of the interaction between people and computers; and

--systems that use inference to apply knowledge to perform a task.

The program is the largest collaborative civil research program that the government has undertaken. Over 5 years, the government plans to spend 50 million pounds (about $72 million) for university research and 150 million pounds (about $216 million) for industry research, with industry providing matching funds. About one-third of program resources were committed in 1983-84. These funds approximately double the government support for these areas. Program management is achieved through a special directorate within the Department of Trade and Industry. In addition to the Department of Trade and Industry, the Department of Education and Science and the Ministry of Defense are also program sponsors. Research projects are to be carried out by consortia normally involving at least two industrial parties, and planners hope that academic and university research establishments will be included in many of the projects. The first major contract, awarded in April 1984, was for software engineering.

Other Department of Trade and Industry Programs

The Department's 1983 funds for electronics and information technology were 54.5 million pounds (about $79 million), of which 85 percent was spent in industry. To help develop electronics and information technology, the Department performs research and supports industrial development of technology in the following ways:

--Government laboratories perform research on large-scale integrated circuits, including materials, design, and fabrication technology.

--The Department supports industrial projects for making integrated circuits, computer-aided design, manufacture and test of electronics, fiber optics and optoelectronics technology, and the application of microelectronics, as well as other areas.

Science and Engineering Research Council

The Science and Engineering Research Council of the Department of Education and Science is the main supporter of university electronics research. In 1983 funds for information engineering were 8.8 million pounds (about $13 million). The Council has established university centers in different aspects of electronics technology. For example, the Edinburgh Central Microelectronics Processing Facility was established to make integrated circuits for its own research and for research at other universities and industry. The Council also supports research at other universities and at its own laboratories.

Ministry of Defense

Electronics is the highest research priority of the Ministry. Ministry funding for R&D specifically identified as electronics was 284 million pounds (about $412 million) in 1983, or 15 percent of all R&D. The Ministry was the main government support for industrial research on semiconductors in the 1950's and 1960's, and its programs still have considerable influence on industry.

Other support

The government has provided extensive financial support to two companies. In 1968 the government provided part of the capital for International Computers Limited, a computer manufacturer. In 1981 the government also guaranteed loans to the company. The government used its funds to start INMOS in 1978, an integrated circuit manufacturer that has established research facilities in the United States.

EUROPEAN COMMUNITY

In 1984, the Community started a R&D program to provide basic information technologies that the European industry needs to compete with the United States and Japan. The program, called the European Strategic Program of Research and Development in Information Technology (ESPRIT), will last 5 years and cost the member governments about $640 million. Industrial corporations participating in the research will contribute an equal amount.

The ESPRIT program is organized around five themes

--development of large-scale integrated circuits in order to stay in competition with Japan and the United States;

--improvements in the theoretical foundation of software technology and in practical application;

--advanced information processing techniques for knowledge representation, methods of deriving facts from data, and inference and deduction techniques;

--the development of office automation technology, which the Community expects will become the largest single information technology market; and

--computer integrated manufacturing systems that will integrate design, manufacturing, engineering, test, repair, and assembly by means of a common data base.

ESPRIT was planned to reinforce the national programs of participating countries and make them more effective. The program is intended to overcome several features of the national programs, including: emphasis on defense-related research that moves slowly into civil application, the short-term focus of industrial research, university research that is inadequately articulated with the needs of industry, and the lack of collaboration among companies in different countries. Therefore, the ESPRIT projects will focus on long-term research, and projects will involve the cooperation of companies, universities, or research institutes in two or more countries.

GOVERNMENT PROGRAMS TO DEVELOP MATERIALS TECHNOLOGY

Materials technology is concerned with the investigation of the properties of materials and in their development for use. A wide range of scientific and engineering fields are involved in materials technology, including polymers, ceramics, and metals, as well as the more general aspects of chemistry and physics. Advances in materials technology can lead to many potential applications of great economic benefit, such as new ceramics that can be used in automobile engines, composite materials for aircraft construction, and strong, light-weight plastics that can replace metals. As a result, there has been increased industrial and military interest and excitement in recent years concerning new ceramics, better metal alloys, and polymeric materials.

UNITED STATES

This section describes materials research and development activities in six U.S. government agencies--DOE, DOD, the Departments of Commerce and Interior, NSF, and NASA. These agencies were identified by Office of Science and Technology Policy staff and agency research managers as conducting R&D most likely to lead to development of new materials technologies. Agencies like DOD, NSF, DOE, and the Department of the Interior provide universities with modern instrumentation and facilities. One of our consultants noted that this modern equipment is necessary for state-of-the-art research. The description of agency activities shows the purpose of the agency research and describes the nature of the agency's materials R&D and the level of funding. Appendix IV contains a more detailed description of agency materials R&D in six specific areas targeted by the Japanese government.

Department of Energy

DOE reports that it performed about $368 million in materials R&D in fiscal year 1982,[1] most of which was in three programs--materials science (26 percent), defense (26 percent), and nuclear energy (29 percent). The remaining materials R&D is performed as part of several other activities, including energy conservation and the development of solar and fossil energy.

The Materials Sciences Division conducts basic research on materials phenomena, properties, and behaviors. About one-third of the research is performed at universities or at DOE laboratories managed by universities, and almost all of the remaining research is performed by other DOE laboratories. Research activities are divided into three main subprograms--metallurgy and ceramics, solid-state physics, and materials chemistry. In addition to its research activities, the Division also manages 13 collaborative research centers at DOE laboratories that are open to outside researchers in universities and industry.

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[1] DOE conducted a detailed study of materials R&D in fiscal year 1982 that was not collected in as much detail in 1983. Data is currently being compiled for fiscal years 1984 and 1985.

About 88 percent of the defense materials R&D is for nuclear weapons, with most of the remainder for waste control. Work is directed toward materials science, materials and fabrication technology, and materials and process development for nuclear and non-nuclear weapons and is conducted primarily at three DOE nuclear weapons laboratories.

Of the $105.5 million in nuclear energy materials research performed in fiscal year 1982, $60 million was in the naval reactor programs and over $27 million was for breeder reactor technology. The remainder was for waste repositories, high-temperature reactors, space nuclear projects, and light water reactors. Naval reactors materials research is for ship propulsion systems. Materials research for breeder technology is to develop economic and safe components and systems.

Other materials research areas include solar energy, ($23.4 million in fiscal year 1982), magnetic fusion and fusion reactors ($15.8 million in fiscal year 1982), fossil fuels ($15.1 million in fiscal year 1982), and energy conservation ($15.1 million in fiscal year 1982). Solar energy research is concerned primarily with applied research on photovoltaic cells. Fusion research is to provide a materials property data base and develop new materials for fusion reactor systems. Fossil fuel research is concerned with a range of subjects, including the corrosion of metals and ceramics, ceramic coatings, and structural ceramics. Most energy conservation materials research is on the use of structural ceramics to make more efficient vehicle engines.

Department of Defense

In fiscal year 1983 DOD identified $296.5 million for materials and structures research in its technology base programs. The Department also develops materials technology as part of weapons systems development, but this work cannot be separately identified. Materials and structures research is managed by the Air Force (40 percent), the Navy (29 percent), the Army (21 percent), and DARPA (10 percent).

DARPA supports research identified as having long-term military benefits. Current research areas include: advanced ceramics, composite materials, optical materials, structured polymers, and armor and anti-armor materials. The programs of three military services are oriented toward more specific application. Overall, about 28 percent of the DOD materials and structures work was devoted to composite materials in fiscal year 1983. Other research areas include advanced metallurgy, ceramics, nondestructive testing and insepction, and fracture mechanisms.

The National Science Foundation

NSF's Materials Research Division[2] supported about $100 million in research, primarily at universities, in fiscal year 1984. About $28 million was for support of 14 university materials research laboratories, $63 million supported research by individual investigators, and the remaining funds supported four research facilities. The Chemical and Process Engineering Division and the Mechanical Engineering and Applied Mechanics Division also support research on materials.

The materials research laboratories at universities, which originated from a program established by the Advanced Research Projects Agency of the Department of Defense in 1960, have been funded by NSF since 1972. They are intended to be central experimental facilities for specific areas of materials technology and perform research requiring a multi-investigator, interdisciplinary approach, which is not usually possible through individual grant support.

The Materials Research Division gives grants to individual faculty members in the disciplines that are part of materials research, including chemistry, physics, mathematics, metallurgy, and chemical, electrical, and mechanical engineering. The research is managed through eight research areas, including metallurgy, ceramics, polymers, solid-state physics, solid-state chemistry, low-temperature physics, and condensed matter theory. The Division also supports the National Magnet Laboratory at the Massachusetts Institute of Technology, radiation facilities at Cornell University and the University of Wisconsin, and a small-angle scattering facility at Oak Ridge National Laboratory. These centers are intended to be widely available to scientists, not just to faculty members of the particular institution.

The Chemical and Process Engineering Division supports the study of fundamental principles, design and control strategies, and mathematical models and experimental techniques identified as having broad potential applicability to the chemical and process industries. Advances in chemical and process technology can be very important to the development of new or improved materials, so the research sponsored by the Chemical and Process Engineering Division is often closely related to research sponsored by the Materials Research Division.

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[2] NSF's organization for supporting engineering research charged in January 1985.

The Mechanical Engineering and Applied Mechanics Division sponsors research on mechanical and production systems. Some of the research relates directly to the development and use of new materials. For example, the solid mechanics element of the program supports research on material damage and failure for materials such as metals, continuous and short-fiber materials, and porous and granular materials. Research has been used to study the strength and life of aircraft structures made from composite materials, according to NSF.

National Aeronautics and Space Administration

NASA has several research efforts directed toward the development and improvement of new materials. These include a materials and structures program, which is part of the agency's research and technology activities, a program to test the use of composite materials in transport aircraft, and a program to experiment with the processing of materials in space. NASA also manages some DOE projects to develop efficient engines that use ceramic parts.

The Materials and Structures program was funded at a level of about $75 million in fiscal year 1983, with most of the work performed by NASA researchers at agency facilities. The aeronautics and space components both focus on basic technological issues and each is divided into research areas that NASA tries to maintain at stable funding levels from year to year. Aeronautics research areas are: advanced materials concepts, life prediction, composites, aeroelasticity, and structures and dynamics. In the space part of the program, research areas are: materials science, space-durable materials, advanced thermal protection systems, advanced space structures, and analysis and synthesis. Aeronautics work receives about 60 percent of the program funds, and space receives the remaining funds.

In 1976 NASA began the Composite Primary Aircraft Structures Program. This program developed and tested aircraft parts made from composite materials. The program is now being completed, and NASA does not anticipate spending any additional money on it. The total program cost from 1976 through 1983 was about $103 million, according to NASA data. NASA started another program in 1984, called the Advanced Composite Structures Technology Program, to develop and test the use of composite materials in larger aircraft parts. Current plans call for termination of the program during 1986.

The Materials Processing in Space Program supports research on how better materials might be produced in space, primarily because of the absence of the force of gravity. Funding for this program was about $22 million in fiscal year 1983. Current research areas include: crystal growth, separation and synthesis of biological materials, fluid flow effects in materials processing, combustion science, and containerless processing techniques.

Department of the Interior-
Bureau of Mines

In fiscal year 1983 the Bureau of Mines (BOM) conducted about $32 million in research on minerals and materials. About $17 million was for extractive metallurgy technology research that provides basic information on fundamental scientific and engineering principles of minerals processing. The remaining $15 million was for materials and recycling technology, which seeks to develop substitutes for imported materials in high-performance alloys and ceramics, investigates better wear and corrosion-resistant properties, and studies recovery and recycling of strategically important materials. In addition, the Bureau's Mineral Institutes program was funded at about $10 million in 1983, and about $1 million of research in the Bureau's research laboratories was funded by other federal agencies and industry.

Department of Commerce
National Bureau of Standards

NBS' Center for Materials Science provides measurements, data, standards, reference materials, and other technical information used for the processing, structure, and performance of materials. In fiscal year 1983 about $12 million was directly appropriated to the Center, and an additional $13 million was received from other federal agencies for work performed by the Center. The Center also receives money from trade associations to computerize information about the characteristics of ceramics and metals. Research is performed by NBS staff.

The Center is divided into five program divisions: metallurgy, polymer science and standards, inorganic materials (ceramics and glasses), fracture and deformation, and reactor radiation (which operates an NBS research reactor). The research consists of basic data collection and measurement work, characterization of materials, and identification of mechanical properties.

PROGRAMS IN JAPAN, WEST GERMANY, FRANCE, AND THE UNITED KINGDOM

Most of the information used in this section was prepared by the Office of Naval Research in the Department of the Navy. We asked the Office of Naval Research, which has offices in London, England, and Tokyo, Japan, to provide information on government materials research programs in Japan, West Germany, France, and the United Kingdom. The Office found that there was no one published source of information on materials research in any of the countries, that there were uncertainties in reported funding levels, and that the government priorities were not easy to evaluate. Most of the information developed by the Office came from publications on foreign research and technology and through visits and reports by its staff members. In addition to the material prepared by the Office, we also used information obtained from U.S. government agencies, foreign governments, and other publications.

The Office of Naval Research staff concluded that Japan, West Germany, France, and the United Kingdom are all trying to plan their advanced materials work with some care. Nearly the same problems and the same opportunities are perceived around the world. The nationally funded programs in the four countries all aim for thorough coordination, have relatively strong funding for materials research, and reflect thorough familiarity with U.S. efforts. Each country has focused on specific aspects of materials research, probably to avoid subcritical efforts with serious under-funding.

The general organizational framework for R&D in each of the four countries is described in appendix I. Therefore, this section focuses on specific aspects of materials research in each country. We highlight research in four areas of materials research: ceramics, composite materials, polymers, and rapid solidification metallurgy. These are areas that have been singled out by high-level studies across the world as expected to have rapid growth in the future. (A description of U.S. government research support for these areas is included in app. V, pp. 66 to 69.)

JAPAN

University research, funded by the Ministry of Education, has been concerned with basic research of an academic nature. Government laboratories act as a bridge between university and industry, establish and refine test methods, gather data, follow world efforts, and perform high-risk research that few industrial laboratories would do. The government also supports some research in industry to bring new or improved products closer to the marketplace. The Japanese government has been particularly active in supporting ceramics research.

Ceramics

There are several government projects concerned with ceramics. Five laboratories within the Ministry of International Trade and Industry perform research related to the development of ceramic structural materials and supporting technologies, three laboratories of the Science and Technology Agency conduct basic research related to ceramic materials, and a research institute in the Ministry of Transport works on ceramic marine engine parts.

The Ministry of International Trade and Industry has also started cooperative research projects with industry. In fiscal year 1981 the Ministry began a 10-year project with 15 companies to develop ceramics as part of a larger project to develop basic technology for future industries (see appendix V for a description of the larger program). Some ceramics research is also being performed as a part of a cooperative project to develop an advanced gas turbine, which began in 1978.

University research is supported by the Ministry of Education, Science, and Culture. In 1982 Japanese researchers identified 17 university ceramics research programs.

Composite materials

The government's major composite materials research program is part of a larger 10-year project to develop technology for basic industries (see appendix V for a description of the larger program). The program is highly collaborative between government and industrial laboratories. Most of the work is done by industrial laboratories, with some university research. Government-sponsored R&D is small in comparison to that of the private sector.

Polymers

The government is supporting three cooperative polymer research projects with industry as part of its larger 10-year project to develop basic technology for future industries (see appendix V for a description of the larger program). In addition, the Science and Technology Agency operates a polymer research project. Although funding information is hard to obtain, the Office of Naval Research believes that Japanese government support for polymer research is greater than that of the three European governments.

Rapid solidification metallurgy

The Ministry of International Trade and Industry and the Science and Technology Agency are both conducting research in rapid solidification technology. Early efforts focused on magnetic materials for the electronics industry, while newer efforts concentrate on high-performance materials for the aerospace and automotive industries.

WEST GERMANY

In 1985 the government plans to begin a 5-year program in materials research. The program, which will receive at least 50 million marks (about $19 million) per year, will include research on structural ceramics, powder metallurgy, composite materials, and polymers.

Ceramics

The Ministry of Research and Technology began a long-range program in ceramics in 1974 to develop high-strength materials. The program involved engine manufacturers, ceramic material producers, university laboratories, and independent research institutes. The program, which ended in 1983, received about 50 million marks (about $19 million) in government funds. A follow-up program was started that emphasizes the reproducibility and reliability of ceramic materials.

Composite materials

The German Aerospace Research Center, a large national research center, is the leader for government composites-related aerospace research. Government priority for composites research is in aerospace and automotive engine and frame applications.

Polymers

In the opinion of the Office of Naval Research, the German research effort in polymers is larger than that of France or the United Kingdom. The government supports substantial polymer research efforts in about 20 universities through the German Research Society. By far the largest university effort is a $1.2 million-a-year project that has been supported for 15 years. University research has been fundamental in character. The government has also supported two research institutes that are more oriented to industrial interests. The Max Planck Society is creating a new Institute for Polymers that will synthesize, characterize, and study polymer properties, and prepare model polymers for other researchers.

Rapid solidification metallurgy

Most government-supported research in this area appears to be at about six universities. The funding level could not be determined.

FRANCE

Over the past few years, the French government has expanded and coordinated its materials research efforts. The government is strengthening several research areas.

Ceramics

Government ceramics research is performed by defense laboratories and laboratories of the National Center of Scientific Research. The government also proposes to establish a ceramics research laboratory to be supported by the government and industry. Funding levels could not be determined.

Composite materials

The National Center for Scientific Research, part of the Ministry of Research and Technology, has designated composite materials as one of six themes for promotion. Within the Ministry of Defense, the National Institute for Aerospace Research and Studies has an active composite research program. The government also supports composites R&D in nationalized industries and is considering a special 3-year effort in composites research at a cost of about 160 million francs (about $20 million).

Polymers

The government supports polymers research in government laboratories, universities, and industry and planned to begin a new program on industrial polymers in 1984. The Office of Naval Research estimates that France conducts less polymer research than Japan and Germany, but about as much as the United Kingdom. However, funding levels for polymer research and development are hard to determine because they are combined with other materials research and even broader areas.

Rapid solidification metallurgy

Amorphous metals, which are part of rapid solidification metallurgy, have been a research theme for the National Center of Scientific Research since 1980. Amorphous metals and microcrystalline alloys, another aspect of rapid solidification metallurgy, are also part of a proposed new government effort. The government emphasizes amorphous metals for use in magnetic alloys and aluminum, superalloy, and titanium powder metallurgy for aerospace and energy applications.

UNITED KINGDOM

The government used its own laboratories to begin work in materials and to lead research programs. Universities perform basic research and interdisciplinary work; many advanced materials concepts have come from this work. Industrial laboratory participation is mainly in applied research.

Ceramics

The Department of Trade and Industry supports ceramics R&D by two government laboratories, an industrial research association, and private corporations. The government is planning R&D work on ceramic parts for automobile engines. Universities are performing research on more fundamental issues like fracture processes, and there is a small defense research effort in ceramics.

Composite materials

The government's leading R&D work in composite materials is on testing mechanical properties and modeling deformation and fracture properties and is performed at government laboratories. In addition, composites research is performed at about 20 universities. Total government funding is roughly 3 million pounds (about $4,330,000) a year.

Polymer research

The Office of Naval Research estimates government support of polymer research at about 8-10 million pounds (about $11.5-$14.4 million) per year. The government has selected several very specific projects for support and also supports more general fundamental research. Research is also supported by the Department of Trade and Industry and the Ministry of Defense.

Rapid solidification metallurgy

Government research in this area includes research at about six universities and at the Ministry of Defense. The Office of Naval Research estimates government funding to be about $721,500.

PROFILE OF U.S. FEDERAL FUNDING LEVELS IN NINE RESEARCH AREAS TARGETED BY THE JAPANESE GOVERNMENT

INTRODUCTION

We were asked as part of our overall study of U.S. and foreign government programs and policies in support of electronics and materials technology to identify U.S. government funding for nine research areas targeted by the Japanese government for long-term research support.

Six of the areas are related to materials technology, while three are part of electronics technology. The six areas in materials are: ceramics, composite materials, polymer separation membranes, conducting polymers, crystalline polymers, and controlled crystal alloys. The three electronics areas are: super-lattice devices, three-dimensional circuit cells, and devices with high resistance to heat and nuclear radiation. (See the glossary for a description of these terms.)

In fiscal year 1981 Japan's Ministry of International Trade and Industry inaugurated the Research and Development Project of Basic Technology for Future Industries. The Ministry project involves conducting R&D in "revolutionary basic technologies" that are perceived as high-risk and that require a considerable investment in both time (generally 10 years) and money. Table V-1 shows approximate funding levels for the first 3 years of the project.

The overall technology areas, under which the nine research areas fall, are identified as New Materials and New Electronic Devices, as shown in table V-1.

Table V-1

Japanese Government Funding Levels for the New Technologies Program[a]

	FY 1981	FY 1982	FY 1983	Total
	(millions)			
New materials	$6.2	$11.2[b]	$13.7	$31.1
New electronic devices	3.1	4.9	6.2	14.2
Total	$9.3	$16.1	$19.9	$45.3

[a] Excludes biotechnology, which is not covered in this report.

[b] Does not include other ceramics research outside of this program, as described in appendix IV.

In order to provide U.S. government funding levels for the nine research areas targeted by the Japanese government, we identified six federal agencies that are funding the bulk of the research in support of their own individual agency missions. These agencies are DOD, DOE, NASA, NSF, NBS, and BOM.

We asked program officials in each of the six agencies to provide current funding levels for the nine research areas. The nine research areas we requested did not always fit exactly into research areas within agency program elements. Therefore, managers often had to estimate the amount of funding applicable to the nine areas we requested. For instance, in DOD, ceramics research may be part of a larger effort to develop composites. A manager had to decide whether to include funding related to this effort under ceramics or composites.

U.S. GOVERNMENT SPENT OVER $200 MILLION FOR FISCAL YEAR 1983 IN NINE RESEARCH AREAS

Estimates we received from six agencies show that in fiscal year 1983 the U.S. government was funding over $225 million for R&D in the nine research areas targeted by the Japanese. As table V-1 shows, the Japanese government committed about $45 million for the nine research areas over a 3-year period.

DEFENSE MISSION HAS MOST U.S. FUNDING

The level of funding the United States is committing to the nine research areas is largely due to defense-related research and development.

Table V-2 shows how the estimated spending for the nine research areas was distributed among the six agencies in fiscal year 1983. DOD is responsible for about 63 percent of the total funding in the nine research areas.

Table V-2
Distribution of Funding for Nine Research Areas by U.S. Government Agencies
(FY 1983)

Agency	New material areas	Electronic devices areas	Total
	(millions)		
DOD	$123.4	$18.9	$142.3
DOE	33.3	14.3	47.6
NASA	18.5	.7	19.2
NSF	8.3	.5	8.8
NBS	4.7	.3	5.0
BOM	3.1	-	3.1
Total	$191.3	$34.7	$226.0

Table V-3 shows how the U.S. government funding for the nine research areas was divided between civilian and defense mission efforts in fiscal year 1983.

Table V-3
Distribution of U.S. Government Funding Levels Between Civilian and Defense Mission Efforts for the Nine Research Areas

	Funding level (millions)	Percent
Civilian[a]	$ 64.4	28
Defense[b]	161.6	72
Total	$226.0	100

[a] Includes NASA, NSF, NBS, BOM, and all DOE programs except defense-related research.

[b] Includes DOD and DOE's defense-related research.

As table V-3 shows, a substantial portion of U.S. government funding for the nine research areas (72 percent) is driven by defense-related program elements. A more detailed funding profile and description of funding in the nine research areas is provided below, with emphasis on those research areas with the largest funding.

THE RESEARCH AREAS OF COMPOSITES AND CERAMICS ACCOUNT FOR OVER 60 PERCENT OF U.S. GOVERNMENT FUNDING

Table V-4 identifies fiscal year 1983 funding levels by both research area and agency. The totals for the nine research areas are ranked from largest to smallest within the categories of materials and electronics.

Table V-4
Distribution of Fiscal Year 1983 Funding for Specific Materials and Electronics R&D Areas Within Six U.S. Federal Agencies

Six Materials Research Areas

(millions)

	DOD	DOE	NASA	NSF	NBS	BOM	Total
Composites	$ 84.0	$ 2.3	$13.9	$0.1	$0.3	$ -	$100.6
Ceramics	15.8	20.0	1.9	2.8	2.3	1.6	44.4
Rapid Solidification	18.7	3.1	2.4	2.6	1.0	1.4	29.2
Polymers-crystal	3.3	5.0	.2	2.0	1.0	-	11.5
Polymers-synthetic	1.6	2.0	.1	.7	-	-	4.4
Polymers-membranes	-	.9	-	0	.1	-	1.0
Total	$123.4	$33.3	$18.5	$8.2	$4.7	$3.0	$191.1

Three Electronic Device Areas

(millions)

	DOD	DOE	NASA	NSF	NBS	BOM	Total
Fortified ICs	$ 6.9	$11.6	$ 0.4	$ -	$0.3	$ -	$ 19.2
Superlattice	8.8	1.0	.3	.3	-	-	10.4
3-D ICs	3.2	1.7	-	.2	-	-	5.1
Total	18.9	14.3	.7	.5	.3	-	34.7
Total	$142.3	$47.6	$19.2	$8.7	$5.0	$3.0	$225.8

The composites and ceramics research areas, with funding primarily within the DOD and DOE mission areas, account for about 64 percent of U.S. government funding in the nine research areas.

Composite materials

The United States supports far more R&D on composite materials than on any of the other research areas. DOD supports about 83 percent of the composites research, while NASA supports 14 percent. DOD activities are for a wide range of military applications, including aircraft, missiles, and armaments. NASA's work is directed toward large aircraft and space vehicles.

DOD spent about $84 million in fiscal year 1983 on composites research as part of its Materials and Structures Technology Base Program. The Army and the Air Force account for over 70 percent of the total amount. DOD emphasizes three areas of composites development: organic matrix composites, which include such materials as fiberglass; metal matrix composites, which have the advantage of low weight, but high strength; and carbon/carbon composites. In the area of organic matrix composites, which has been funded since the early 1970's, the Air Force interest is in light-weight materials for small aircraft. Currently, the area of organic composites comprises two-thirds of total departmental funding in the composites research area, while the newer areas of carbon/carbon and metal matrix composites together comprise 33 percent of DOD's research in composite materials.

Since the mid-1970's, NASA has performed and supported research on the use of composite materials in large transport aircraft. NASA's Composite Primary Aircraft Structures Program ran from fiscal years 1976 to 1983 at a cost of about $103 million. NASA requested approval for a new program in Advanced Composite Structures Technology in fiscal year 1984, which is intended to provide a composite structure engineering data base for large civil and military aircraft of the 1990's.

Ceramics

While the government's composites research is overwhelmingly in defense-related areas, the effort in ceramics R&D has had a large nondefense component. As table V-4 shows, DOE accounted for approximately 45 percent of the government's funding effort in ceramics in fiscal year 1983. DOD also houses a relatively substantial amount of funding in ceramics.

The government's research emphasis in ceramics in general has been on the development of structural ceramics, which can be used in automotive engines. The advantages of using ceramics parts are that they are lighter and rustless and can operate at higher, more efficient temperatures. Much current testing involves the ability of ceramic material to withstand extremes of temperature.

Since the mid-1970's, DOE has been funding research on the gas turbine engine and more recently, on the diesel engine. Some of DOE's funds have been managed by NASA's Lewis Research Center, where ceramics testing is performed. Both NASA and DOE sponsor research initiatives in ceramics that are coordinated, but funded separately.

DARPA currently accounts for over half of total DOD spending in ceramics, while the three military services spend the remaining amount. In fiscal year 1983 about $7 million in ceramics funding was housed within NBS, NSF, and BOM, the remaining three agencies doing research in this area. NSF supports basic university research ($2.8 million), NBS does research on materials characterization and measurement ($2.3 million), and BOM directs ceramics research as part of its Material and Recycling Technology Program ($1.6 million).

Rapid solidification metallurgy and polymers research

About 15 percent of the funding in the six materials research areas went to rapid solidification technology in fiscal year 1983. Over half of this amount is housed within DOD. The objective of the DOD research is to develop and demonstrate the effectiveness of rapidly solidified metal powder processing technology. Defense research on rapid solidification technology is for applications like helicopter engines, missiles, and weapons.

In fiscal year 1983 crystalline polymers were the largest of the three polymer research areas, 43 percent of which was in DOE's defense application research area. A relatively low level of research has been devoted to polymer membranes and conducting polymers. According to a DOE official who compiled polymer estimates for us, this relatively low level for polymer research within DOE's budget is changing. Several DOE advisory committees perceive that polymers will play an important role in long-term materials needs.

Electronics research and development

Table V-4 shows the fiscal year 1983 U.S. federal funding effort in the three electronic research areas targeted by the Japanese government. Fifty-one percent of the overall funding in these three research areas is in fortified integrated circuits, almost all of which is funded by DOD and DOE.

Fortified integrated circuits research involves the development of electronic devices resistent to environmental conditions such as nuclear radiation. Within DOE, for instance, research in fortified integrated circuits (fiscal year 1983 funding was $11.6 million) is carried on primarily for military weapons. Within DOD, the Air Force mission is to develop and maintain a technologically advanced electronic base in support of advanced military systems requirements. In this regard, integrated circuit technology has focused on the development of high-speed information processing and high-speed signal processing. DARPA estimates that $4.1 million of its research in fiscal year 1983 was related to the development of electronic devices that are resistant to nuclear radiation. This research is on the use of gallium arsenide to make integrated circuits that are lightweight and require low power levels for space use.

Super-lattice materials and three-dimensional techniques for integrated circuit production are approaches to making faster and larger operating integrated circuits. DOD and DOE sponsor almost all of the government research in these areas for use in military applications.

NASA is conducting a modest electronics research program in the areas of super-lattice devices, radiation effects, and high temperature semiconductors for space sensors and communications and for aircraft applications.

GOVERNMENT POLICIES AFFECTING PRIVATE SECTOR RESEARCH AND TECHNOLOGY

Studies have identified ways that government may affect industry's spending for R&D, including taxes, antitrust requirements, incentives for capital investment, patent procedures, and regulatory activities. Because studies have identified these areas as ways government can influence private sector R&D, we conducted a limited survey of published material to obtain information about statutory provisions concerning these areas in the United States, Japan, West Germany, France, and the United Kingdom. We were not able to identify published material that described or analyzed how the statutes were implemented in the different countries.

It is important to note that our discussion says nothing about the effects of countries' policies on R&D activities. R&D activities are affected by many conditions besides the policies described in this chapter. For example, isolating the influence of some particular tax or antitrust provision on R&D activity is a complex and uncertain task, well beyond the scope of this appendix. Moreover, the conditions that affect R&D activity vary across the five countries, so similar policies will have different effects in different countries. One condition of particular importance is the extent of public ownership of industry. While this is relatively low in the United States, nationalized industries are more common in other countries. The application of tax and antitrust laws can have different effects on public versus private companies. In addition, the significance of government efforts to direct the flow of private capital toward R&D differs under different degrees of nationalization.

TAXES

All five countries have tax provisions that affect private sector R&D, for the most part encouraging it. Some provisions are aimed specifically at R&D while others affect it only indirectly. There are differences among the countries in the types of provisions used (e.g., not all countries employ investment tax credits) and the formulation of these provisions (e.g., depreciation rules differ). However, the countries' tax treatments of R&D are similar. Only the United States has some provisions not shared by the other countries.

Tax provisions affect the flow of funds toward R&D activities by affecting the after-tax profitability of either the projects themselves (e.g., depreciation rules), or investments that provide funds for R&D (e.g., capital gains taxation). The effects of the more common provisions follow.

Depreciation rules and tax credits

Depreciation allowances and tax credits can stimulate R&D in two ways. First, by reducing cost and increasing the value of R&D relative to other uses of a business' cash, they may encourage the business to substitute R&D for other activities. This is particularly true for depreciation and credit provisions that are specifically aimed at R&D. Second, depreciation allowances and tax credits may increase a business' cash flow if there is taxable income. (So might the taxation of dividends as explained under dividends below.) With more discretionary funds available, businesses may undertake projects that they otherwise could not afford.

In 1981 the United States introduced a special tax credit that applies specifically to R&D expenditures through 1985. The Economic Recovery Tax Act of 1981, P.L. 97-34 created a special tax credit for certain R&D expenditures that was effective after June 30, 1981 and expires in 1985. The credit is 25 percent of any increase in current-year eligible expenditures over a base period amount. The base period amount is the annual average of all eligible expenditures for the previous 3 years. However, it can be no less than 50 percent of current-year expenditures. Investment expenditures that are ineligible for this special tax credit, whether related to R&D activities or other investment projects, may be subject to the normal investment tax credit of 10 percent.

Capital gains

Preferential tax treatment of long-term capital gains theoretically fosters capital investment. If this happens more funds may be made available for R&D and other corporate activities. In the United States, all personal short-term realized capital gains (those on assets held for less than six months) are taxed as ordinary income, but only 40 percent of long-term capital gains are so taxed. The rest are tax free. Net capital losses can be deducted from taxable income. However, this deduction is limited to a maximum of $3,000 each year. Capital losses above the allowed maximum can be carried forward into future tax years.

Dividends

Double taxation of dividends, coupled with preferential capital gains taxation, can induce firms to retain earnings, thus making more funds available for R&D. Dividends are doubly taxed when the corporate income from which they are paid is fully taxed, and the dividends themselves are taxed as income of the receiving stockholders. Since 40 percent long-term capital gains is taxed as ordinary income, stockholders might be better off if firms retain earnings (which may increase stock values) rather than pay dividends. In this way, the firms' cash flow increases and more money is available for R&D.

Savings

Interest earned on savings is taxed as ordinary income in some countries but not others. When savings are taxed as ordinary income, taxpayers have less incentive to save, thus making less money available to those who want to borrow for R&D projects. However, savings may not be eliminated but simply diverted into areas where taxes are lower, such as municipal bonds. The detrimental effects of taxing the interest earned on savings are mitigated to the extent that diverted funds find their way into R&D projects.

Tax exempt organizations

Donations made to nonprofit research organizations are tax deductible. Such organizations are also tax exempt. These provisions may increase donations to these organizations.

Special U.S. provisions

In the United States there are tax provisions that apply to small business investment companies (SBICs), multinational corporations, and certain other firms that qualify. The last provision is available to firms engaged in R&D when they have no more than 35 stockholders. In general, all stockholders must be U.S. citizens. A firm electing this tax treatment enjoys some of the tax advantages available to unincorporated enterprises, but retains the limited liability of a corporation.

SBICs may provide funds to small businesses by buying their convertible debentures. This encourages R&D to the extent that small firms engaging in R&D receive SBIC funds. The tax advantages accorded SBICs that induce them to invest in small firms are:

--Losses on stocks in an SBIC are treated as ordinary losses, rather than offsetting them against gains on stocks.

--Losses in converting debentures are handled similarly.

--The normal 85-percent deduction for dividends received is increased to 100 percent.

Another tax advantage for individuals or partners, is that losses on small business stock can be treated as ordinary (i.e., not capital) losses, under certain conditions. This could also induce investors to divert funds toward small business.

Some regulated investment companies provide funds to firms that are chiefly involved in developing new products or processes. The Securities and Exchange Commission certifies these investment companies as venture capital companies. This certification confers a tax advantage on these companies since they pay no taxes on dividends distributed to their stockholders. Investing money in R&D activities is thus made more attractive to the venture capital companies and, in turn, their stockholders.

ANTITRUST POLICIES

In our review of antitrust policies we relied mainly on OECD publications. Our review indicates all five governments have anti-trust provisions to influence firms' behavior but that there are differences among the countries in the specific policies and procedures that are used. Each country regards agreements among competing firms as an area of antitrust concern, but considers how their provisions might affect the public interest. The countries all take a rough costbenefit approach to this problem. Joint ventures having possible anticompetitive effects are sanctioned if these effects appear to be outweighed by their benefits. The relationship between antitrust policies and R&D activity is a complex issue that we are constrained to treat in a condensed way.

United States

According to a Justice Department official the National Cooperative Research Act of 1984 (P.L. 98-462, 15 U.S.C. 4301) was passed to promote research and development and encourage innovation. The act uses three methods to achieve its goals. It states clearly that when research and development joint ventures are challenged as being anticompetitive the courts shall use a rule of reason standard for determining whether they are illegal. According to the Conference Report, this standard is to include consideration of the ventures' pro-competitive effects and condemn only anticompetitive joint ventures.

The act limits the recovery of damages for violation of the antitrust laws to actual damages instead of treble damages if the group conducting the joint research and development venture notifies the Attorney General of the United States and the Federal Trade Commission of their activities in accordance with this law's provisions. In addition, a substantially prevailing party in a joint venture suit may recover attorney's fees under specified circumstances.

Japan

According to OECD anticompetitive actions are generally prohibited under the act concerning prohibition of private monopoly and maintenance of fair trade (Act No. 54, April 14, 1947), as amended (June 3, 1977). However, exceptions are made for "rationalization cartels." These exceptions are generally provided for in the act itself and, pursuant to particular industries and situations, by special legislation.

Rationalization cartels formed specifically to encourage joint R&D do not face the same government scrutiny as do those formed for other purposes, according to a study by the U.S. International Trade Commission. While antitrust exemptions are available for joint R&D ventures, they are generally not required. The government agency responsible for approving rationalization cartels, the Fair Trade Commission, will not challenge joint R&D ventures as long as no Japanese firm with an interest in the venture is excluded from it or its results. Further, the Commission believes that joint R&D ventures do not usually restrict technology and therefore do not violate competition law.

West Germany

Antitrust legislation generally prohibits agreements among companies that may restrain competition, according to OECD. This general principle is stated at the beginning of West Germany's primary antitrust statute, the Act Against Restraints of Competition, passed on July 27, 1957. Section 1(1) of Chapter 1 (Cartel Agreements and Cartel Decisions) states:

> "Agreements made for common purpose by enterprises or associations of enterprises and decisions of associations of enterprises shall be of no effect, insofar as they are likely to influence, by restraining competition, production or market conditions with respect to trade in goods or commercial services. This shall apply only insofar as this Act does not provide otherwise."

Joint research agreements are among the so-called rationalization cartels that have been submitted to the Federal Cartel approved, it must lead to a better performance for the same price, or to a lower price for the same performance. It may also qualify if the supply of some good or service is made possible (or is at least facilitated) by the rationalization cartel. In comparing the restraint of competition with the beneficial effects of the joint activity, the cartel authority must consider how much competition between the parties is excluded and the strength of competition from those outside the agreement.

France

According to OECD, antitrust legislation is concerned with R&D efforts in two respects. First, the legislation seeks to prevent the disruption of technological advance that might result from firms' anticompetitive actions. Second, potential benefits from increased productivity can justify anticompetitive actions that would otherwise be found illegal.

Legislation on restrictive business practices is contained in Price Ordinance 45-1483 of June 1945. One article delineates the types of anticompetitive actions that are likely to be found illegal. Another discusses the exceptional circumstances that would justify an otherwise illegal action or situation. Both articles apply to agreements or combines among firms and the activities of a firm or firms having a dominant position in some industry.

United Kingdom

Responsibility for antitrust administration is shared among four bodies, according to OECD. Monopoly and merger situations are referred to the Monopolies and Mergers Commission for consideration. These referrals are made by either the Secretary of State for Prices and Consumer Protection or the Director General of Fair Trading. The Commission is an advisory body only. Enforcement of antitrust sanctions is left to the Secretary of State. The Commission does offer advice, however, and in doing so it considers the effects of the situation on the public interest. This consideration includes the desirability or promoting reductions in costs and development of new techniques and products. Restrictive trade practices are the concern of the Restrictive Practices Court. Upon application by the Director General, the court can declare whether restrictive trade agreements among identified suppliers are contrary to the public interest.

INCENTIVES FOR CAPITAL INVESTMENT

Government incentives for private capital investment can encourage R&D by making money available to start new, innovative firms or expand older ones. All countries have nontaxable provisions for private capital investment, but they take different forms. The U.S. government provides incentives to create venture capital companies that provide financing to firms performing R&D. The Defense Department's Manufacturing Technology Program provides money to demonstrate "factory floor" application of new or improved technology to produce defense items.[1] In 1982 the government began the Small Business Innovation Research Program, which provides money to small businesses for research projects so that they may later attract private investments.[2] The West German and French governments focus on loans subsidies and guarantees, since firms tend to raise capital investment by borrowing rather than by selling stock. The Japanese government assumes the default risk for some new ventures by providing partial financing, thereby inducing private lenders to participate. The United Kingdom gives financial assistance through loan guarantees, low interest rate loans, and equity. However, these programs are now being reduced.

PATENT PROCEDURES

Patent procedures can influence the private sector's incentive to perform R&D and introduce and diffuse new technologies. We found several basic similarities among all five governments in the granting of patents.

--Each government grants patents that give the owner the exclusive right to make, use, or sell his invention for a specified time period.

--Each government recognizes only its own patents. Therefore, an inventor must apply for protection in each country where he wants to reserve his rights to his patent.

--Foreign inventors are required to follow the same procedures and receive the same protection as nationals in each country. (However, most of the countries require that foreigners appoint a representative living in the country.)

--Each government requires an examination to determine whether an invention is new before it issues a patent.

There are also differences in the patent procedures of the five governments. The United States will only grant patents to the first person to invent or his legal successor, while Japan, West Germany, and France will grant the patent to the first person to file for it. The United Kingdom will grant the patent to the first person to invent or to anyone who imports the invention holders to make use of the patent and provide for compulsory licensing. All countries except the United States permit third parties to comment on inventions through formal opposition proceedings.

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[1] Information on this program is contained in our report, DOD Manufacturing Technology Program--Management is Improving But Benefits Are Hard To Measure (GAO/NSIAD-85-5, 85-5a, Nov. 30, 1984).

[2] The authorizing legislation requires GAO to report on this program by 1987.

All countries require "novelty" examinations of which there are two types--immediate and deferred examinations. After an application has been filed and examined for formal requirements, it is examined for substance (i.e., novelty, patentability, level of invention activity) immediately in the United States and the United Kingdom. This examination is deferred in France up to 2 years and in West Germany and Japan up to 7 years.

Patent life is 20 years in all countries except the United States, where it is 17 years. According to the Patent and Trademark Office, patent life begins from the date of issuance in the United States. It begins with the date of application (filing) in the United Kingdom, West Germany, and France. Patent life in Japan is 15 years, beginning from the time that data examination is completed or from the date the application is published, not to exceed 20 years. There is usually an 18-month lag between the date of application and the date of publication in Japan.

REGULATORY POLICIES

Regulatory policies can affect R&D activity. These policies include environmental regulations, worker health and safety regulations, health and safety standards for consumer products, rate-of-return regulation of public utilities, and the regulation of entry and market behavior of firms in certain industrial sectors like transportation.

Such regulations can inhibit R&D activity in four ways. Regulations can: increase the cost of research, product development, and commercialization; create uncertainty about future costs and revenues from R&D projects; reduce above-normal profits needed to stimulate R&D activity; and reduce the present value of net benefits from R&D projects by creating delays. Cost increases can result, for example, from requirements to install pollution-control equipment. Uncertainty can be increased because regulatory decisions are difficult to predict and conditions can change with little notice. Rate-of-return regulation is one example of above-normal profits reductions that can result from regulations. As a result, public utilities may have reduced incentives for R&D. Finally, delays in product approval for a new drug, for example, can reduce the profitability of R&D ventures since costs may not be delayed but revenues may be put off for many years. These and similar effects can reduce R&D activity in all of the countries.

There are also some offsetting effects of regulations that could increase R&D activity. First, the need for new products and processes to comply with regulations may only be satisfied by considerable R&D efforts. The development of pollution-control equipment is one area where this may have occurred. Second, the enforcement of certain regulations may be conducive to R&D activity. For example, public utilities typically can include the cost of R&D efforts in their rate bases, even if these efforts fail. This reduces the costs of R&D for these firms. Profitability can be further increased if regulators are more concerned with controlling prices rather than rates-of-return. Cost-saving innovations then become potentially profitable to the regulated firm and R&D activity is correspondingly increased.

Despite the pervasiveness of regulations and their potential effects on R&D, we did not make cross-country comparisons of regulatory policies for a number of reasons. First, the effects of regulations on R&D efforts are uncertain and difficult to identify. The relative magnitudes of both negative and positive effects are not known and the probable net effects of each country's policies are impossible to gauge. Second, the number of regulations that would have to be inclued in our discussion is impossibly large. The topic is too broad and diffuse to fit within the scope of this report. Third, there is no way to assess the effects of similar regulations in different countries since the economic settings vary. Comparing dissimilar regulatory policies would be even more difficult. Finally, a lengthy discussion of the potential adverse effects of regulation on R&D can be interpreted as advocating repeal of such regulations. This is particularly true within the context of this report. The fact that regulations can have many beneficial effects (e.g., a cleaner environment, safer workplaces) can get lost in such a discussion, and a fair, balanced treatment of the entire issue is beyond the scope of our effort.

METHODOLOGY

In preparing this report, we used many different information sources as described below. We did not try to independently verify data. Consultants and other experts knowledgable about electronics and materials technology and research programs and about government policies to support technological innovation reviewed the draft report. Changes in the draft to incorporate their comments were made where appropriate.

To compare total national expenditures on R&D, we used data published by the Organization for Economic Cooperation and Development and the United States' National Science Board. We also used some unpublished data which the National Science Foundation staff obtained from the OECD and individual foreign governments. OECD data are compiled from reports made by individual countries according to standard definitions published by OECD. Because OECD data are compiled from several countries, the latest comparable data is often several years old. Where necessary, NSF staff converted foreign currencies to U.S. dollars by procedures developed by OECD that adjust exchange rates to reflect actual purchasing power.

In preparing information on the overall organization of the Japanese, West German, French, and United Kingdom governments for R&D and on their electronics programs, we relied most heavily on government publications, supplemented by other publications where appropriate. We used translations of foreign newspapers prepared by the U.S. Joint Publications Research Service and other U.S. government publications and also obtained some unpublished material through embassies in Washington, D.C. We also interviewed U.S. government officials, representatives of foreign governments, and academic researchers. In reporting on these specific foreign government programs, we used the original source's dollar conversions from foreign currencies source when they were present and used exchange rates published by the Department of Commerce when they were not. Conversion rates were used for the last quarter of the year stated.

At our request, the Office of Naval Research, Department of the Navy, prepared information on governmental materials R&D programs in Japan, West Germany, France, and the United Kingdom. The Office has staff in Tokyo, Japan, and London, England. In preparing information for us, the Office used publications on foreign research and technology and information collected through visits and reports made by Office staff members and discussions with embassy staff in Washington. The Office noted that there were uncertainties in the reported funding levels, which were made in the local currency. We converted local currency to U.S. dollars using the published Deparment of Commerce rate for the last quarter of the year stated.

Information on U.S. governmental R&D was obtained from budget justifications and other published materials; unpublished government documents, and interviews with officials in the Office of Science and Technology Policy; the Departments of Commerce, Defense, Energy, Interior, and State; the National Aeronautics and Space Administration; and NSF. We also interviewed academic researchers and representatives of professional organizations.

In order to provide U.S. government funding levels for the nine research areas targeted by the Japanese government, we identified six federal agencies that are funding the bulk of the research in support of their own individual agency missions. These agencies are the Department of Defense, the Department of Energy, NASA, NSF, NBS, and BOM.

We asked program officials in each of the six agencies to provide current funding levels for the nine research areas. The nine research areas we requested often did not fit exactly into research areas within agency program elements. Therefore, managers often had to make an estimate of the amount of funding applicable to the nine areas we requested. For instance, in DOD, ceramics research may be part of a larger effort to develop composites. A manager had to decide whether to include funding related to this effort under ceramics or composites.

We also surveyed publications concerning governmental activities that may affect R&D by private industry. In the survey we reviewed published material and statutory provisions concerning taxes, antitrust requirements, incentives for capital investment, patent procedures and regulatory activities. We were not able to identify published material that described or analyzed the effect of each statute's implementation in the different countries.

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Administration
Washington, D.C. 20230

APR 24 1985

Mr. J. Dexter Peach
Director, Resources, Community, and
Economic Development Division
United States General
Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

This is in reply to GAO's letter of March 20, 1985, requesting comments on the draft report entitled "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom."

We have reviewed the enclosed comments of the Director of the National Bureau of Standards and believe they are responsive to the matters discussed in the report.

Sincerely,

for
Kay Bulow
Assistant Secretary
for Administration

Enclosure

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Gaithersburg, Maryland 20899
OFFICE OF THE DIRECTOR

APR 11 1985

Mr. J. Dexter Peach
Director, Resources, Community, and
Economic Development Division
U. S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

Thank you for the opportunity to comment on the draft audit report entitled Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom.

The only comments we have are editorial and pertain to Appendix III, page 32.

First paragraph, line 4, delete the word "centers" and insert the word "organizations."

> Both organizations work . . .

Second paragraph, line 2, delete the word "standards."

> forms research and development on . . .

Second paragraph, line 5, change "$11" million to "$12" million.

Second paragraph, line 6, change "$7" million to "$10" million.

Second paragraph, line 7, change the word "five" to "four."

> . . . is divided into four program areas:

Second paragraph, lines 8, 9, and 10, rewrite to read as follows:

> "electrosystems, electromagnetic interface, fast signal metrology, and semiconductor material process and device metrology."

Third paragraph, line 1, insert the following phrase after the word "which":

> which performs research, develops standards, and advises federal agencies . . .

Third paragraph, line 6, delete the word "prototype."

and standards for . . .

Third paragraph, last line, delete the word "subjects" and insert the words "areas of computer technology."

other areas of computer technology.

Sincerely,

Ernest Ambler
Director

GAO NOTE: Page numbers in this appendix that referred to the draft report were changed to reflect their location in the final report. The comments were included in the final report.

THE UNDER SECRETARY OF DEFENSE
WASHINGTON, DC 20301-3010

RESEARCH AND
ENGINEERING

2 MAY 1985

Mr. Frank C. Conahan
Director, National Security and
International Affairs Division
United States General Accounting Office
441 G Street N.W.
Washington, D.C. 20548

Dear Mr. Conahan:

The General Accounting Office (GAO) draft report entitled, "Support for Development of Electronics and Materials Technologies by the Governments of the United States, West Germany, France and the United Kingdom," dated March 27, 1985 (GAO Code No. 974195), OSD Case No. 6718 has been reviewed by this office.

The Department of Defense concurs with the draft report and has no recommended changes.

Sincerely,

James P. Wade

James P. Wade, Jr.
Acting

Department of Energy
Washington, D.C. 20585

APR 25 1985

Mr. Mark Nadel
Resources, Community and Economic
Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Nadel:

In response to Mr. J. Dexter Peach's request of March 20, 1985, the Department of Energy's formal comments on the General Accounting Office (GAO) draft report entitled "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France, and the United Kingdom" are being submitted by separate letter to the GAO.

Editorial comments on the report are enclosed for GAO's consideration in preparing the final report.

Sincerely,

Dolan

Martha Hesse Dolan
Assistant Secretary
Management and Administration

Enclosure

Editorial Comments on the GAO Draft Report "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France, and the United Kingdom" (GAO/RCED-85-63).

1. page 7 - "In the United States, there is no single agency with broad responsiblity for supporting the development of technology for use by industry, while the National Institutes of Health, the National Science Foundation, and the Departments of Defense and Agriculture support significant amounts of university research."

   Comment - Suggest adding the Department of Energy since it is one of the largest supporters of physical science research at universities and university-related research through support of central facilities used primarily by university researchers.

2. page 13/14 - "The Japanese government spent about $14 million in these areas in 1983."

   Comment - This is too low and misleading for comparison with United States funding. The Japanese funding levels generally do not include salaries and overhead. Our information indicates that Japanese annual funding at four national laboratories in just one of the six materials technologies (ceramics) is about $27 million.

3. glossary p. 5 - "Conducting polymers...polymers that conduct electricity. The only known polymer that inherently conducts electricity is sulfur nitride $(SN)_x$."

   Comment - Suggest adding: but, some are superconducting, i.e., have no resistance to current flow at the appropriate superconducting temperature.

Appendix I

4. page 2 - "Table I-1, National Expenditures for Research and Development"

   Comment - This table is misleading. Since a comparison among countries is being sought, suggest adding in the table the ratio of civilian to defense funding.

Appendix II

5. page 15 - "The National Science Foundation (NSF) provides general support for research at universities, while the four other agencies conduct research related to their specific function."

   Comment - Suggest adding after specific function: at government laboratories, industry, and universities.

6. page 15 - "The Department of Energy (DOE) develops nuclear weapons and performs research in high energy physics and energy technologies."

   Comment - Suggest adding after high energy physics: nuclear physics, health and environmental sciences, basic energy sciences, and energy technologies.

7. page 16 - "For example, the Department of Agriculture develops agricultural technologies, NASA conducts research to advance aircraft technology, and the Department of the Interior conducts research and development programs in support of the mining and mineral processing industries."

   Comment - Suggest adding after aircraft technology: the Department of Energy develops energy technologies.

8. page 16 - "Four agencies sponsor 90 percent of the federal government's support for university research..."

   Comment - Since the subject of the report contains significant DOE involvement, suggest adding DOE under agencies which support research at universities. The DOE support at universities is approximately $350 million.

9. page 16 - "The federal government does not support general university operating costs, as is the case in some other countries."

   Comment - This is misleading. Suggest inserting the word, directly, after "does not."

10. page 17 - "Three agencies share broad responsibilities for science and technology activities in Japan."

    Comment - This is misleading since most research in Japan is supported in private foundations such as NEDO (New Energy Development Organization).

Appendix III

11. page 25 - "Governments plan to use very large scale integrated circuits to advance computer capability for purposes such as artificial intelligence, computer-aided design and manufacturing, and robotics."

    Comment - Suggest adding after robotics: and large scale scientific computation.

12. page 33 - "Most DOE research and development of electronics technology is for military purposes. The cost of research is about $30 million a year. Most research is performed in government-owned laboratories specializing in weapons work."

Comment - Suggest adding second paragraph:

> DOE also supports research in applied mathematics and computer science aimed at advancing fundamental knowledge about large scale scientific computational processes necessary for understanding the physical processes underlying many DOE research and development programs. This program cost about $15 million in FY 1984 of which 60 percent was at DOE laboratories and 40 percent at universities. The research supports software engineering, design of parallel algorithms, architecture and software, and computational mathematics for large scale scientific computing.

13. page 37 - "One study identified six universities with significant computer science and engineering programs."

Comment - This is misleading since there are many universities involved in this research in Japan. Suggest adding before "six", at least.

Appendix IV

14. page 47 - "Government agencies like DOD, NSF, and the Department of the Interior provide universities with modern instrumentation and facilities."

Comment - Suggest adding DOE to the list in view of the fact that DOE is the major supporter of large scientific facilities used by universities especially in areas related to this report.

15. page 48 - "[a]Department of Energy conducted a detailed study of materials research and development in fiscal year 1982 that was not repeated for fiscal years 1983 or 1984."

Comment - Suggest correcting this statement to ..."fiscal year 1982 and 1983 and is presently being compiled for FY 1984 and FY 1985."

16. page 56 - "In 1982, Japanese researchers identified 17 university ceramics research programs."

Comment - This is probably incorrect. Suggest changing to: ..."identified many ceramics research programs at more than 17 universities."

17. page 60 - "Industrial laboratory participation is mainly in applied research to develop improved products."

Comment - This is misleading since it is known that significant ceramics research is conducted by private industry. Suggest simply ending the sentence after "applied research."

18. page 64 - "Table V-2, Distribution of Funding for Nine Research Areas by U.S. Government Agencies"

Comment - The funding values in the table may be misleading since the table is dominated by one figure, DOD spending in new materials areas, and there may be differences in definitions especially in this area. Suggest adding a note to that effect.

19. page 66 - "Table V-4, Distribution of Fiscal Year 1983 Funding for Specific Materials and Electronics R&D Areas within Six U.S. Federal Agencies"

Comment - The table may be misleading because of differences in definitions. For example the DOE value for ceramics funding could vary between a few million dollars and 100 million dollars depending on definition. Suggest adding a footnote to that effect.

20. page 68 - "Both NASA and DOE are planning major research initiatives in ceramics which will be coordinated, but funded separately."

Comment - Suggest correcting to: Both NASA and DOE have major research initiatives in ceramics which are coordinated, but funded separately.

GAO NOTE: Page numbers in this appendix which referred to the draft report were changed to reflect their location in the final report. Except for the following, the comments were included in the final report.

Comment 4: We agree that it is important to portray the relationship of civilian to defense funding. Our approach was to highlight nondefense funding in a separate chart (Chart I-2).

Comment 10: We did not include private foundations within the scope of our work. Our statement refers to the governmental organization in Japan.

Comments 13, 16, 18, 19: These comments refer to the need to show uncertainties in the data. It is important to show uncertainties in the data, but we believe that the existing report language has necessary qualifications and portrays the uncertainties.

United States Department of the Interior

OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

APR 22 1985

Mr. J. Dexter Peach
Director
Resources, Community, and Economic
Development Division
General Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

In compliance with Public Law 96-226, we have reviewed the draft GAO report entitled, "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France, and the United Kingdom" (GAO/RCED-85-63).

In general, your comparative descriptions of the various government research support activities for the five countries appear to be reasonably accurate, and the report highlights many of the differences between the countries. We are in agreement with the overall thrust of the report relating to the need for the United States to improve its competitive position in the international marketplace, particularly in the "high-technology" areas upon which other industrial countries are focussing their efforts.

However, we offer a few enclosed comments that may be helpful to you in preparing your final report.

Sincerely,

Bob Broadbent

Robert N. Broadbent
Assistant Secretary
for Water and Science

Enclosure

Department of the Interior Response to Draft Report Prepared
by the Staff of the U.S. General Accounting Office

"Support for Development of Electronics and Materials
Technologies by the Governments of the United States,
Japan, West Germany, France, and the United Kingdom"

In general, your comparative descriptions of the various government research support activities for the five countries appear to be reasonably accurate, although no reference is made to participation in EEC and NATO materials research programs. Greater emphasis could be made in describing Japan's significant large industrial research activity, due in part to its large-scale hiring of engineers and scientists that is made easier by low salary structures and low interest rates. There is also a close relationship of Japanese industry to research institutes and universities. In the U.S. activities section, you omitted mention of electronics research in the Department of Transportation and the significant amount of "Independent R&D" work by Defense contractors which is paid for by the Federal government as an overhead item.

In regard to your reference to the Bureau of Mines on page 16, you state that "the Department of the Interior conducts research and development programs in support of the mining and mineral processing industries," giving the impression that this is its sole responsibility. The Bureau also has a significant responsibility in materials conservation research, conducting investigations on substitution, recycling, and longer-lasting materials important to national productivity, national security, and energy conservation.

The last sentence on page 16, "The Federal government does not support general university operating costs, as is the case in some other countries," should be clarified because the Federal government does support some operating costs in the overhead charges allowed on university grants and contracts.

On page 53, the description of Bureau of Mines activities should include its Mineral Institutes program, which in fiscal year 1983 was funded for approximately $10 million. In addition, the research in minerals and materials was augmented by approximately $1 million from other sources--both other Federal agencies and industry--for work performed in the Bureau's research laboratories.

GAO NOTE: Page numbers in this appendix that referred to the draft report were changed to reflect their location in the final report. The comments were included in the final report.

United States Department of State

Comptroller

Washington, D.C. 20520

April 15, 1985

Dear Frank:

I am replying to your letter of March 21, 1985 which forwarded to the Department for review and comment copies of the draft report: "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom."

The Department has reviewed the report and finds it both accurate and responsive to the Senator's request.

We appreciate having had the opportunity to review the draft report.

Sincerely,

Roger

Roger B. Feldman

Mr. Frank Conahan
Director,
National Security and
International Affairs Division,
U.S. General Accounting Office,
Washington, D.C. 20548

NATIONAL SCIENCE FOUNDATION
WASHINGTON D C 20550

Office of Budget, Audit,
anc Control

April 16, 1985

Mr. J. Dexter Peach
Director
Resources, Community, and
Economic Development Division
U. S. General Accounting Office
Washington, DC 20548

Dear Mr. Peach:

We appreciate the opportunity to comment on the draft GAO report, "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom." The report is consistent with what the NSF staff knows of the plans and activities of the various countries. Enclosed are some detailed suggestions on specific wording and some additional information which may be useful.

Sincerely yours,

J H Fregeau
Jerome H. Fregeau
Director
Division of Audit and Oversight

Enclosures

UNITED STATES GOVERNMENT

memorandum

DATE: April 11, 1985

REPLY TO ATTN OF: Acting Staff Associate, STIA

SUBJECT: Draft GAO Report on "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom

TO: Director, Audit and Oversight Branch

This is in response to your request that the STIA staff review the subject GAO report and furnish appropriate comments.

According to our specialists in the International Programs division, the report material is consisent with what they know of the various country plans and activities. In general, the data contained in the report is a year or two behind the times. They felt that the glossary of technical terms is a useful feature. It was also noted that NSF was not listed among the abbreviations and that the correct title for the French Ministry is Ministry of Research and Technology (see page 20). The INT specialists also felt that GAO should be advised to carefully review and reference the JTECH reports on the four Japanese technology areas of materials, biotechnology, opto and micro electronics, and computer science.

Staff from the PRA and SRS divisions furnished the attached comments which should be useful to the GAO authors. Also attached are related statistical reports and data furnished by SRS that may also be of use to GAO. SRS also marked up the attached draft report.

Please call me if we can be of further assistance in this matter.

Thomas M Ryan
Thomas M. Ryan

Attachments

GAO NOTE: We updated our report with the data provided by NSF, received the available JTECH reports, and included NSF in the list of abbreviations.

4/12/85 #22

OPTIONAL FORM NO. 10
REV. 1-80
GSA FPMR 41 CFR 101-11.6
5010-114

GPO : 1984 O - 433-783

UNITED STATES GOVERNMENT

memorandum

DATE: April 9, 1985

REPLY TO ATTN OF: Frank Huband, PRA/TRP, Room 1229

SUBJECT: Review of Draft GAO Report

TO: Thomas M. Ryan, STIA

As requested, we have reviewed the draft of the report, "Support for Development of Electronics and Materials Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom". A few comments follow: (1) Generally the report is interesting and contains a substantial amount of useful data. (2) NSF does not appear with the other funding agencies in the ABBREVIATIONS section on the unnumbered page following the table of contents, giving the impression at that point that NSF is not a player in the field. (3) The engineering programs at NSF have recently been reorganized--the old terminology is used in the draft. (4) The NSF Divsion of Policy Research and Analysis has recently received reports from two of its contractors that could be useful to the GAO in their further development of this subject. They are "High Technology Ceramics in Japan", available from the National Academy Press, and "JTECH Panel Report on Computer Science in Japan", available from Science Applications International Corporation, La Jolla, California.

Frank Huband
Section Head
Technology and Resources
Policy Section

Attachment

GAO NOTE: We added NSF to the abbreviations section and reviewed the reports identified by NSF. We also added an explanatory note describing NSF's reorganization of its engineering programs.

OPTIONAL FORM NO. 10
(REV. 1-80)
GSA FPMR (41 CFR) 101-11.6
5010-114

* U.S. GOVERNMENT PRINTING OFFICE : 1982 O - 361-526 (8017)

UNITED STATES GOVERNMENT

memorandum

DATE: April 9, 1985

REPLY TO ATTN OF: Acting Division Director, SRS

SUBJECT: Review of GAO Report

TO: Tom Ryan, STIA

At your request, we have reviewed the attached draft of the GAO Report on Support for Development of Electronics and Material Technologies by the Governments of the United States, Japan, West Germany, France and the United Kingdom. Specific comments and corrections are noted in the text. Our review was concentrated on the overall report and appendices I and II. Data in the other sections could not be checked as they are estimates provided by numerous sources in the U.S. and abroad.

In addition to the comments written on the draft itself, I have the following overall suggestions and comments:

In many cases there are more recent numbers available. You will find that we have updated or revised much of the data and incorporated these within the text. I am also sending several of our reports which provide such updated information.

More references should be used as to the source of data or statements especially for the discussion of foreign investments and policies.

There are a great many difficulties in determining what should be included in estimates of R&D investments in these new technology areas -- both for the United States and foreign countries. Greater emphasis should be placed on the difficulties of making such estimates and problems of comparability across countries. The report would also benefit from a more thorough explanation of how the estimates were made, what was included, etc.

U.S. defense R&D spending does support advancements in the high technology areas addressed. The defense-civilian discussion might be softened.

The NSB has not officially adopted the civilian R&D definition as the only one. In fact, we are moving to a nondefense R&D concept. Text is changed accordingly.

On pages 8 and 10 a number of statements are made which allude to U.S. or Japanese superiority without noting that the Soviet Union has larger investments or degrees. Either mention this or note that these comparisons pertain only to the five countries examined.

OPTIONAL FORM NO. 10
(REV. 1-80)
GSA FPMR (41 CFR) 101-11.6
5010-114

✩ GPO : 1983 O - 421-526 (9176)

NSF generally includes agricultural sciences among total natural sciences and engineering degrees; they are included in the life sciences. Table I-3 should probably show agricultural degrees separately since they are considered a science field.

Table II-1 which shows government R&D expenditures by objective, has been updated in the case of the United States and corrected in the case of Japan and the United Kingdom to show distributions with the advancement of knowledge category excluded as this was GAO's intention. GAO might want to note that in 1981, the advancement of knowledge category constituted 52.3 percent of government funds in Japan; 42.3 percent in Germany, 24.1 percent in France; and 26.6 percent in the United Kingdom; compared with only 4.0 percent in the United States.

W L Stewart
William L. Stewart
Acting Division Director, SRS

Attachments

(974195)